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THESIS

ECONOMIC ANALYSIS OF ALTERNATIVES
FOR
PC UPGRADE OF OR DEPARTMENT LABORATORY

by

Chen Lung-Shan

September, 1990

Thesis Advisor:

Thomas E. Halwachs

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Economic Analysis Of Alternatives For PC Upgrade Of OR Department
Laboratory

by

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Major, Republic Of China On Taiwan Army
B.S., Defence Management Institute, 1980

Submitted in partial fulfillment of the requirements
for the degree of

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ABSTRACT

The Operations Research Department at the NPS plans to upgrade the hardware of the Personal Computer (PC) laboratory. The objective of this thesis is to analyze the potential upgrade paths dependent upon hardware availability, software compatibility, maintenance and initial cost. The alternatives are: (a) to upgrade the existing Zenith with a 80386 (CPU), (b) to buy the UNISYS desktop III system or (c) to purchase the DELL SYSTEM-310. The study utilizes the economic cost/benefit approach to examine the alternatives and to develop recommendations. The principles of economic analysis are reviewed. The results of survey of user's opinion are analyzed to establish the requirements for upgrade. The result of economic analysis shows the UNISYS system to be the cheapest and most system-effective. The price of each unit is an undiscounted \$2,176 or discounted \$1,994 for five years of economic life and is within the budget available. The sensitivity analysis reveals (a) by break-even analysis, the economic life parameter is insensitive, (b) the cost reduction parameter is also insensitive, and (c) the discount rate is also insensitive. Therefore the recommendation is that the UNISYS system be chosen.

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I. INTRODUCTION

A. BACKGROUND

The Operations Research Department plans to upgrade the hardware of the Personal Computer (PC) laboratory in the next fiscal year. The objective of this thesis is to analyze the potential upgrade paths dependent upon hardware availability, software compatibility, maintenance and initial cost. The alternatives are: (a) to upgrade the existing 80286 (CPU) Zenith Z-248 AT with a 80386 (CPU), (b) to buy the UNISYS desktop III system under the 17 November, 1989 DOD contract: "DD1155", or (c) to purchase the DELL SYSTEM-310, rated the highest in a survey by PC-magazine. The study will utilize the economic cost/benefit approach to examine the alternatives and to develop the recommendations.

1. The Current System Environment

The Operation Research Department of the Naval Postgraduate School operates a micro-computer laboratory for classroom instruction and student research in Root Hall, Room 262. The existing Novell network provides the capability to link the Network File Server and all PCs to the IBM 3033 mainframe located in Ingersoll Hall as well as to other network systems around the campus.

The laboratory contains Zenith Z-248 AT systems with application software programs. The hardware and software are described in Tables 1.1 and 1.2, respectively.

Item	Description
(Hardware) 1. Zenith Z-248 AT-clones: (20 units)	Each unit includes : a. 80287 Math coprocessor b. 20 MB hard drive c. 360k floppy drive d. 512k expansion RAM e. EGA color monitor
2. Printers:	a. 4 ALPS 2000 DOT-MATRIX b. 1 HP LASERJET II c. 1 HP LASERJET 500+

Table 1.1 The Description Of Existing Hardware In The PC Laboratory

Item	Description
(Software)	Wordperfect is fast becoming the universal standard for word-processing
1.WORDPERFECT * (version 5.1)	
2.STATGRAPHICS * (version 4.0)	This is a combination of STATistics analysis and GRAPHICS display software program
3.GAMS * (version 2.05)	GAMS:General Algebraic Modeling System is designed to construct and solve large, complex mathematical programming models.
4.APL * (version 9.0)	APL (A Programming Language) is an extremely concise and powerful programming language.
5.LINDO *	LINDO (Linear, INteractive, Discrete Optimizer) is used for solving Linear Programming (LP) problems.
6.HARVARD GRAPHICS * (version 2.12)	This software program is used for creating presentation charts.

Table 1.2 The Description Of Existing Software In The PC Laboratory *¹

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To provide consistency with the current system environment (hardware and software as shown in previous tables), it is assumed that no major changes in size or type of facilities are planned.

2. PC Laboratory Requirements

In order to get concise user information on laboratory requirements, the survey form was designed as shown in the Appendix A. It was issued to the sixth and eighth quarter Operations Research students in February 1990. An analysis of the survey results is presented in Chapter IV.

3. The Comparison Of 286 And 386 System

Since 1984, when the IBM Corporation introduced the PC/AT 286 system, the Intel 80286 processor has been a tremendous success. Even though 286 systems are still being sold, it may be timely to replace with a 386 system. For example as "Computer Shopper" of May 1990 says: "While new 386 and 486 systems constantly get most of the press coverage, 286 systems still continue to sell like crazy. The market research from Dataquest (a consulting company bulletin) estimates that a record 6.6 million 286 systems were sold in 1989" [Ref. 3: p.132]. However, the new powerful DOS software of the '90s' will be written to take advantage of 386 32-bit systems. The article continues "If you're certain that you won't want to run any software five years from now, then the 286 is still a safe choice. But you'll probably end up upgrading again in the years ahead. It's better to spend a little more money now and save yourself from obsolescence" [Ref. 3: p. 133] . The key differences between the 286 and 386 system are shown in the Table 1.3.

Key Feature	80286 system	80386 system
1.FPU(Floating Point Unit):	Only Intel 80287	Intel 80287 and 80387
2.Clock:	Lowest : 8 MHZ Highest : 16 MHZ	Lowest : 16 MHZ Highest : 33 MHZ or more
3.Address Space:	65,536 Bytes (64 K Bytes)	4,294,967,296 Bytes (4 Giga Bytes)
4.Multitasking :	Not Available	Available
5.Memory Management: (protected and unprotected)	Not easy to move between modes	Easy to move between modes

Table 1.3 Key Comparisons For 80286 And 80386 Systems ²

² FPU(Floating Point Unit) is required for non-integer computer computation. (In C and Pascal programming language, the most important data types are the integer, the character, and the pointer. In Fortran, most data types are either integer or real. In Cobol, the major data types are string, integer, and fixed point. Ada covers all previous data types). The Intel 80387 FPU is IEEE-754 standard and its function is more powerful than previous 80287 FPU. [Ref. 1: pp. 207-215 and Ref. 2: pp. 299-305].

At the same clockspeed, the relative speed of 80386 system is about 1.4 times over that of 80286 system. Both systems are compared to a speed benchmark equal to 1 of an IBM-AT 8 MHZ system. [Ref. 3 : p.133]

B. ALTERNATIVES

The method of purchasing is a major factor in acquiring new computer hardware under existing regulations in the government. When a DOD GSA contract exists, acquisition of equipment can be accomplished in a more timely manner. However, superior functions of some non-GSA equipment that meet the requirements of the budget limit, performance standard, and expected life cycle may dictate going through the competition process for the upgrade. An analysis of the computer market, new computer trends, our PC laboratory budget and current/future laboratory requirements, have identified three systems which meet the stated conditions. The systems identified are compared in Chapter II.

C. ASSUMPTIONS

The following assumptions have been made: (a) the general operational ability of each alternative is equal, (b) the systems are compatible with the existing installed network, and (c) the existing application software can be successfully migrated to the new 386 system. However, this thesis will identify any information obtained that indicates these are not valid assumptions.

D. CONCLUSIONS

The analysis contained in the following chapters leads to the recommendations of the UNISYS DESKTOP III as the cost effective choice for the PC laboratory.

II. THE SYSTEM CHARACTERISTICS OF EACH ALTERNATIVE

Detailed characteristics of the hardware and software for each system are presented in this chapter. Descriptions follow in each subsection and a summary comparison is given in the final section of this chapter. Cost and maintainability will be addressed in a later chapter.

Current and future applications in the OR PC laboratory require that the existing software packages be successfully migrated to the new 386 system. Also, new software package (e.g., APL-2) must work in the system environment. Finally, the new system must have a good management environment that includes virus detection software that will run from start up to prevent transfer of a virus from floppy disks. The software should be able to give warning messages to the user and an abort/reject command at the insert action.

A. DESCRIPTIONS

1. UNISYS System

The UNISYS corporation was awarded the "Desktop III"--(CT3) micro-computer contract by DOD on 17 November 1989. CT3 provides a source for 80386 DOS and UNIX based desktop system software, and associated peripherals with attractive prices. The Air Force Standard System Center at Gunter Air Force Base, Alabama, has completed the Function Test Demonstration (FTD) of the Desktop III hardware and software supplied by UNISYS corporation and has accepted the system. The hardware characteristics and software characteristics of a UNISYS system

selected by the author to meet the OR PC laboratory requirements are shown in Tables 2.1 and 2.2.

Item	Description
1. Workstation:	a. Advance workstation: PW2 800/20 (20 MHZ 80386) with 80387 math coprocessor. b. 2MB memory. c. Serial mouse. d. System keylock w/2 keys. e. 3.5 inch 720KB/1.44MB floppy drive with box of ten 1.44MB diskettes. f. SCSI adapter, 2 serial ports and parallel port. g. 101 key keyboard. h. 200 watt power supply.
2. Monitor:	14" VGA color monitor (640 x 480)
3. Video Board:	VGA video board (640 x 480)
4. Harddisk drive:	42 MB SCSI internal hard drive, 19 MS, 8 MB Bits/sec

Table 2.1 Hardware Characteristics Of UNISYS System

Item	Description
1. Operating system:	MS-DOS 4.01
2. Utilities and diagnostic softwares :	<ul style="list-style-type: none"> <li data-bbox="793 579 1291 706">a. Windows 386 V2.11 MS-DOS Memory Manager. <li data-bbox="793 727 1193 770">b. MS-DOS Disk Manager. <li data-bbox="793 791 1291 833">c. MS-DOS Disk Caching Utility. <li data-bbox="793 854 1280 897">d. MS-DOS diagnostic softwares. <li data-bbox="793 918 1230 960">e. POSIX diagnostic software.

Table 2.2 Software Characteristics Of UNISYS System

2. Zenith (Z-248) CPU And Monitor Upgraded System

For this alternative, the 286 system board and memory board need to be removed for installation of the ZX-386 with daughter board. VGA monitors and VGA boards must be purchased to upgrade the existing Zenith (Z-248) system. The features of new system are described as following Tables 2.3 and 2.4.

Item	Description
1. Workstation:	a. Intel 8 MHZ 80286 microprocessor b. 1.1 MB RAM expandable to 3 MB. c. Socket for an 80287 coprocessor:Z-416-2. d. 5.25" 360k diskette drive. e. combination floppy/harddisk drive controller. f. 2 parallel and 2 serial ports. g. Enhanced 101 Key Board.
2. Monitor:	ZCM-149-Z VGA 14" Flat Technology Monitor (FTM)
3. Video Board:	Z-549 VGA Video Board (640 X 480)
4. Harddisk drive:	20 MB harddisk drive.

Table 2.3 Hardware Characteristics Of Zenith System

Item	Description **
1. Operating system :	MS-DOS
2. Utilities and other software:	<ul style="list-style-type: none"> a. MS-Windows. b. MS-Macro Assembler MS-5063-21. c. MS-Fortran Compiler MS-5063-2. d. MS-Cobol Compiler MS-5063-3. e. GMS-GW Basic Compiler MS-5063-4. f. MS-Pascal Compiler MS-5063-5. g. C Compiler CI-5063-1. h. SUPERCALC-3 SC-5063-3 (Spread Sheet). i. CONDER-III CD-5063-3 (data base).

Table 2.4 Software Characteristics Of Zenith System

** This software is included in the existing Zenith (Z-248) system and can be migrated to either alternative.

3. DELL-310 System

The DELL Computer Corporation, located in Austin, Texas, has a distinguished survey rating from PC-magazine, February 1989. The hardware and

software characteristics of the DELL SYSTEM-310 for the OR-PC laboratory requirements are shown in the Tables 2.5 and 2.6.

Item	Description
1. Workstation:	<p>a. Intel 20 MHZ 80386 microprocessor</p> <p>b. 2 MB RAM expandable to 16 MB using a dedicated high speed 32 BIT memory slot.</p> <p>c. Advanced Intel 80385 Cache Memory Controller with 32 KB of high speed static RAM cache.</p> <p>d. Socket for a 20 MHZ coprocessor: Intel 80387 or WEITEK 3167.</p> <p>e. 5.25" 1.2 MB or 3.5" 1.44 MB diskette drive.</p> <p>f. Dual diskette and hard disk drive controller.</p> <p>g. 1 parallel and 2 serial ports.</p> <p>h. Enhanced 101 Key Board.</p> <p>i. 200 watt power supply.</p>
2. Monitor:	DELL 14" color monitor
3. Video Board:	16 bit, Video adapter (640 X 480)
4. Harddisk drive:	40 MB

Table 2.5 Hardware Characteristics Of DELL-310 System

Item	Descriptions
1. Operating system:	MS-DOS 4.01
2. Utilities and other software:	<p>a. 2 Window Development Systems: (both develop X window applications)</p> <p>(i). Motif window Development system based on OSF/Motif OSF/Motif window manager.</p> <p>(ii). X11 Window Development system.</p> <p>b. Software Development System : includes C compiler, linker, assembler and symbolic debugger.</p> <p>c. TCP/IP Networking System facilitates host-bases protocol processing.</p> <p>d. PC interface MS-DOS Bridge. (is required to run Dell Unix System V --harddisk must at least 100 MB), to act as a file server.</p>

Table 2.6 Software Characteristics Of DEL-310 System

B. COMPARISON

The previous descriptions show that there are similar hardware and software characteristics for each of the three systems. A comparison summary is described in Table 2.7. (In this table, ** means that the upgraded Zenith system will not change the original Z-248 harddisk capacity, software, or utilities).

Main features	UNISYS system	Zenith upgraded	DELL-310 system
(Hardware)			
1. Processing speed	20 MHZ	20 MHZ	20 MHZ
2. Memory(RAM)	2 MB	2 MB	2 MB
3. Hard disk drive	42 MB	20 MB (for ZWX-246-62) **	40 MB
4. Monitor/board	VGA(640 x 480)	VGA(640 x 480)	VGA(640 x 480)
5. Mathematics coprocessor	80387	80287 but 80387 available	80387
6. Keyboard type	101 key advanced	101 key advanced	101 key advanced
(software)			
1. Operating system	MS-DOS 4.01	MS-DOS 4.01	MS-DOS 4.01
2. Diagnostic software	supplied	available	available
3. Special Utility software:	a. SCO UNIC system V setup. b. MS-DOS Disk Disk caching.	set up caching in ROM	set up caching in ROM

Table 2.7 Comparison Summary Of Each System

All three systems contain the key features of a modern 386 system. The hardware includes a 20 MHZ processing speed from a 80386 type CPU (or equivalent), with about 2 MB memory, at least a 20 MB hard disk and a VGA monitor. Software included with each package are MS-DOS 4.0 operation system (or

equivalent).

A cursory look at the required options that the three systems provide show that:

1. The UNISYS system provides two types of diagnostic software: MS-DOS and POSIX, whereas diagnostic software is not supplied with the Zenith and DELL system.
2. Both UNISYS and DELL-310 system have substantial harddisk space for existing and future software packages, however, the new Zenith system only supplies a 20 MB harddisk drive, which may be too small for OR-PC laboratory needs given the requirements of newer application software.

Major advantages and disadvantages of the systems are discussed below:

1. Advantages of the UNISYS system include: (a) a completed integrated workstation, (b) slightly more storage in the hard disk drive when compared to Dell-310 system (42 MB vs 40 MB), but more than twice that of the upgraded Zenith system (42 MB vs 20 MB). Additionally, the purchase of the UNISYS system or DELL-310 system will allow re-utilization of existing Z-248 computers within the OR department.
2. A potential disadvantage of the upgraded Z-248 is the age of existing components, power supply, keyboard, and monitor.

C. SUMMARY

1. Uncertainty about maintenance must be considered: if the Dell system is chosen, the XEROX corporation provides major maintenance. A similar situation exists with the upgraded Zenith system with AMI providing maintenance for the Zenith. However, the UNISYS company has duty officers in California. The service

employees will be dispatched and can perform on station services within 24 hours of notification. [Ref. 22]

2. Performance in terms of speed and expansion of application software based on the 386 system is similar among the three systems. There would be additional training/maintenance requirements if a mix of UNISYS, Zenith and Dell systems were purchased. A mix is therefore not considered for the laboratory.

3. Key remaining points are measurable cost (including procurement, training and maintenance) and the expected benefits in terms of different "ilities" including (a) operational suitability (satisfaction degree of users), (b) operational effectiveness (the new machine works effectively as intended), (c) operational availability (can the new machine in the actual operational environment operate satisfactorily), (d) maintainability (within a given time frame the machine can be returned or restored to working condition), (e) supportability (including the technical support, personnel support, and repair parts support), etc.

4. Safety is an important factor and is required for all 386 system environments. Besides the sufficient documentation of normal and emergency operational manuals, system back-up procedures are required in case of a system crash. An example is the crash resulting from the earthquake of October 1989.

III THE MAIN FEATURES OF ECONOMIC ANALYSIS

The aim of this chapter is to illustrate the definition, use, advantages and limitations of economic analysis. In addition, key steps in the process of economic analysis will be addressed for use in later chapters.

A. INTRODUCTION AND DEFINITION

Economic analysis is concerned with problems of economic choice. It is based on the assumption that each decision has alternative ways to accomplish a goal (or mission) successfully. Economic analysis is a process used to assist the decision maker in meeting resource allocation (budget, time, etc.). Further, for a given environment, economic analysis is a systematic approach of evaluating the relative value (or cost) of each alternative [Ref. 5: p. 1-1]. In a real environment, constraints and criteria are used to assess and compare each alternative. Decision makers must investigate alternatives and consider the costs, benefits, and uncertainties of each.

When an alternative (or alternatives) is/are chosen, sometimes the decision maker must use trade off analysis (e.g., advantages and disadvantages) by considering costs and benefits.

Therefore the concept of economic analysis can be summarized as follows: (a) economic analysis is a decision aid, (b) economic analysis is a systematic approach for assessing alternatives, and (c) economic analysis provides a tool to decrease the uncertainty of the decision maker by considering the costs and benefits of the alternatives. [Ref. 6: pp. 26-27]

In executing economic analysis, three principles must be considered: (a) alternatives must be both technically and operationally feasible, (b) the analysis must consider both the current and future cost and benefit patterns of all alternatives, and (c) because there exists a "time value of money", each alternative must be assessed not only by the current cost (procurement), but also by the expenditure of future costs (maintenance). By analyzing the expected Life Cycle Cost (L.C.C.) of all alternatives in terms of Present Value (P.V.), the best choice may be made. [Ref. 5: p.1-1]

B. USES OF ECONOMIC ANALYSIS

A designed procedure is important. A simplified procedure to recognize the actual problem and to develop several alternatives for solving the problem is shown in Figure 3.1. [Ref. 1: p. 6] This procedure can help determine whether the problem is a real problem or is based on incomplete or incorrect information rendering an invalid analysis.

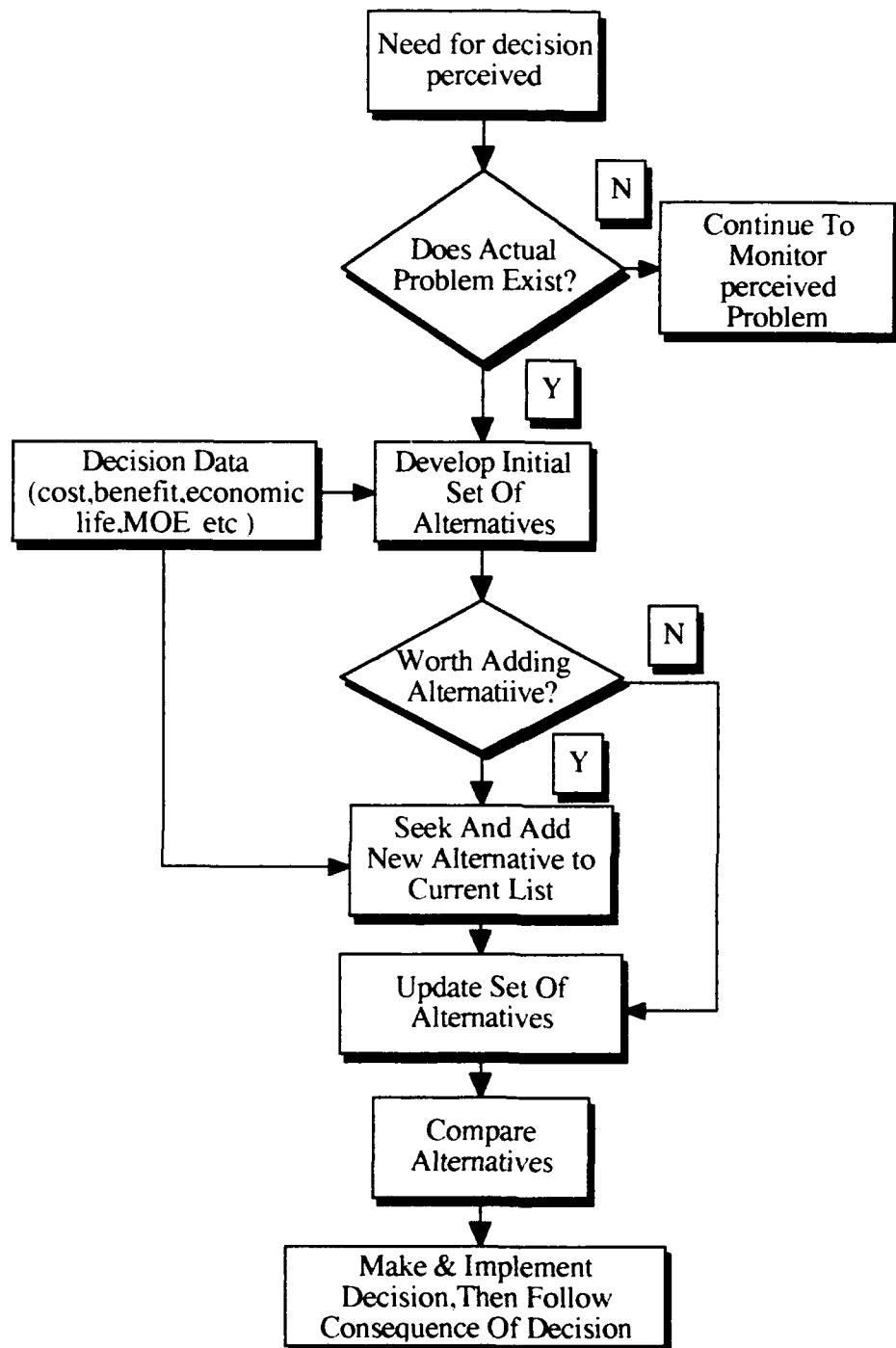


Figure 3.1 A Simplified Procedure For Developing Alternatives

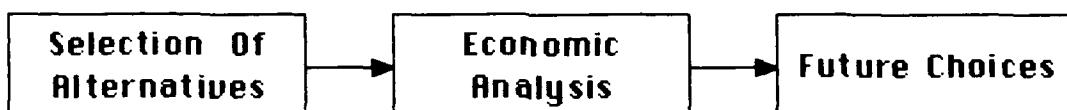
Normally, economic analysis can be applied in two different aspects, (a) to estimate the economic consequence of a decision already made, or (b) as a portion of the initial decision making process. Figure 3.2 demonstrates the difference.

Figure 3.2: Uses Of Economic Analysis

Estimate: Use Economic Analysis To Access The Consequence
Of Past Decisions



Choice: Use Economic Analysis To Estimate The Consequence
Of Future Choices



The second use, "choice", involves decisions on the economic consequences of two or more alternatives. In this situation, the decision should not be made until all costs and benefits of each alternative are estimated. [Ref. 6: p.29] This thesis is of this type.

Economic analysis is a tool by which alternatives can be quantified to assist the decision maker, although it is not an absolute determinate of a particular course of action or project. The decision maker must also interpret the results of

the analysis in conjunction with any additional information (for example, political constraints) that may not have been included in the analysis.

The use of economic analysis can result in a better allocation of resources through improved visibility of the economic impact of programs and projects. Since economic analysis is a general procedure, it can be used to help decision makers solve a wide range (from simple to complex) of problems concerned with economic consideration.

Economic analysis can also be useful in determining future funding requirements. It can serve as visible evidence to administration performing the review and approval process that all economic factors having a bearing on the recommended decision have been considered. It also plays a role in project documentation. Further, as Department Of Defense (DOD) instruction 7041.3 points out:

....Assessment of program evaluation and choice of economic analysis studies will be initiated as early in the acquisitive process as practical and be updated as significant developments occur which could invalidate or significantly alter the cost-benefit relationships upon which previous decisions were made. Evaluation should be updated to consider changes as: (a). actual performance data at variance with predicted performance data, (b). major changes in initial study assumption, and (c). new competing alternatives which are introduced or about to enter the acquisition cycle. [Ref. 6: p. 4]

According to previous instructions, this thesis will deal with economic analysis before making the decision, whether to purchase a brand new 80386 system (UNISYS, or DELL-310), or to upgrade the existing Z-248 system to 80386 level.

C. ADVANTAGES OF ECONOMIC ANALYSIS

Several advantages may be acquired from economic analysis. Among these advantages are: (a) a precise statement of objects to identify the intent of study, (b) with a clear statement of assumptions, economic analysis can support the problem and its implications, (c) economic analysis can aid the decision makers to ascertain all resources required to accomplish a given goal or mission, (d) because economic analysis is a systematic approach, a variety of alternatives can be analyzed to solve a particular problem. These factors allow the decision makers a broad range of information with which to make their decision, and (e) because economic analysis can be illustrated by attractive graphics, a good simplified communication framework can be provided for all participants--analysts, decision makers, budgeteers and program managers. [Ref. 9: p. 33]

D. LIMITATIONS OF ECONOMIC ANALYSIS

Economic analysis has several limitations. First, because economic analysis does not normally assign priorities among goals, the decision makers can only determine the most cost effective methods to satisfy a given objective. Second, economic analysis is a decision making tool and used as an input to the decision making process of choosing the most effective method. Sometimes even when the best outputs of economic analysis are gained, non-economic factors, such as morale, environmental impact, political consideration, etc., will restrict or decrease the efficiency of the decision. Briefly, economic analysis is not a substitute for good judgment. Further, by systematically analyzing what is quantifiable, the decision makers can focus the judgement more sharply on the areas where qualification cannot point out the "best" decision by itself. Third, the

original input data (e.g., historical cost data, the economic life cycle of alternative itself, etc.) is more valid than the result of an economic analysis. A "beautiful" economic analysis model or "best" analysis can result but if data errors were included, then the time was wasted and the resulting analysis may be viewed as just only a "GIGO" (garbage in garbage out). A more careful formation of assumptions and judicious estimations of costs and benefits can result in a successful economic analysis. Finally, because economic analysis necessarily involves assumptions and sometimes future critical events whose outcomes are not known with certainty, the uncertainty cannot be eliminated completely no matter how careful the analysis is. The obvious goal of the economic analysis is to decrease the uncertainty and to deal with it in a rational manner. [Ref. 8: p. 1.3]

E. PROCESS OF ECONOMIC ANALYSIS

Economic analysis is a systematic conceptual framework for systematically portraying, quantifying, and estimating the relative value of proposed alternatives to meet a given objective. The six-step diagram in Figure 3.3 shows the relationships of the elements of the basic economic analysis process. The steps are: (a) establishing and defining the objective, (b) formulating proper assumptions, (c) seeking alternatives for accomplishing the objective, (d) determining the costs(inputs) and the benefits(outputs) for each alternative, (e) comparing the costs and benefits of the alternative, and (f) performing sensitivity analysis. [Ref. 8: p. 2.1-2.6]

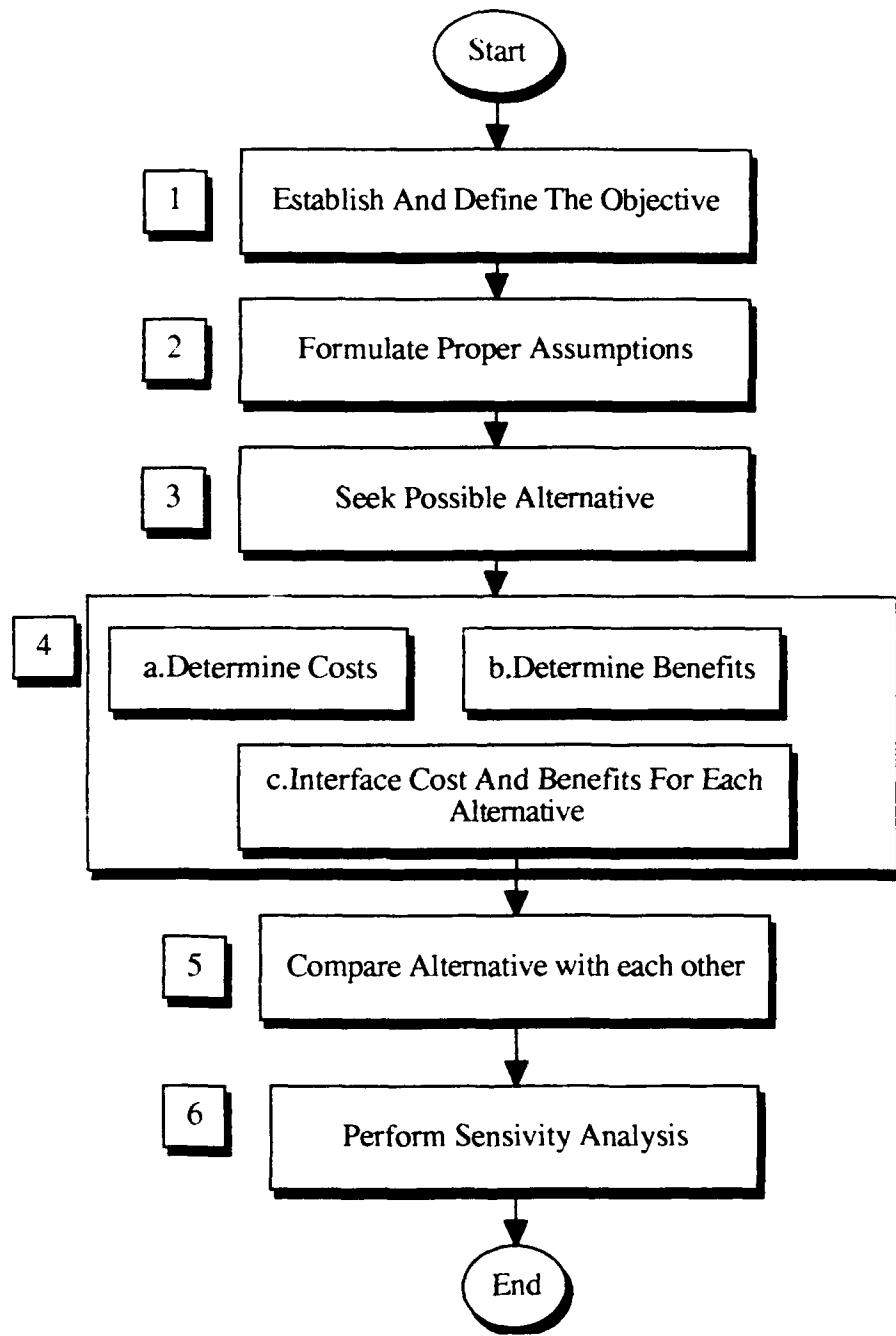


Figure 3.3 Basic Economic Analysis Process

The first three steps of economic analysis were stated in Chapter I. Step-1, "establishing and defining the objective" is the most important step in the economic analysis process. An erroneous or incomplete objective definition can result in a waste of time, material and manpower and lead to a false or erroneous decision. By stating a clear objective in terms of missions or goals, such defects can be eliminated. Step-2, "Formulating the proper assumptions" deals with future expenditures and thus involves elements of uncertainty, so the purpose of assumptions is not to limit the analysis, but to reduce often extremely complex problems to manageable proportions. Step-3, "Seeking possible alternatives" considering all feasible means to meet the objective by stating the technique and operational characteristics of each alternative. In developing alternatives, the current system will serve as a baseline with which to compare new alternatives.

F. SUMMARY

This chapter has presented an overview of economic analysis. First, economic analysis is a systematic procedure, useful for choosing among alternatives to determine the most cost effective alternative (e.g., choose an alternative which has less cost for the same benefit as compared to other alternatives), given a particular mission or goal. Second, by applying economic analysis, the scarce resources (budget, time, manpower, etc.) can be allocated properly and provide a good simplified communication framework for all participants--analysts, decision makers, budgeteers and program manager. Third, the resource data (e.g., historical cost data) is important and must be collected properly and correctly. Otherwise even with a good analysis model, an invalid analysis may result and lead to erroneous decisions. Lastly, the

economic analysis is a general, step by step process which the decision makers can easily follow.

IV. ECONOMIC ANALYSIS OF ALTERNATIVES

The purpose of this chapter is to continue developing the last 3 steps (step 4-6) in the economic analysis process. A survey analysis will be stated in the beginning. Instead of using a cost-benefit analysis method, a cost-effectiveness method will be applied to determine the Life-Cycle-Cost (L.C.C.) and system-effectiveness for each alternative. After the Life-Cycle-Cost (L.C.C.) and system-effectiveness have been determined, a sensitivity-analysis will be carried out to address uncertainty. In addition, a final comparison analysis including recommendations will be given at the end of this chapter.

A. SURVEY ANALYSIS

In order to get more objective user information, the author designed a survey form as shown in Appendix. It was issued to sixth and eighth quarter OA students in February, 1990. The survey, which had a return rate of about 70%, highlighted several facts regarding the configuration of the PC system environment. First, Figure 4.1, "Software usage percentage at OR-PC laboratory" points out that WORDPERFECT is the most popular software with the students (28.72%), since the students start thesis work in the sixth quarter. Second, Figure 4.2, "Analysis of user satisfaction degree for each software" shows that slow speed is the biggest drawback of the Z-248 system. From the bar chart, over 40% of the users complained of slow speed (WORDPERFECT 40.7%, GAMS 75%, LINDO 50%, HARVARD GRAPHICS 66.66%, APL and STAGRAPHICS are highest at 87.5%). In addition, because the Zenith Z-248 AT is only a 16 bit PC-AT machine, it is inconveniently slow, especially when the users run power calculation problems involving simulation.

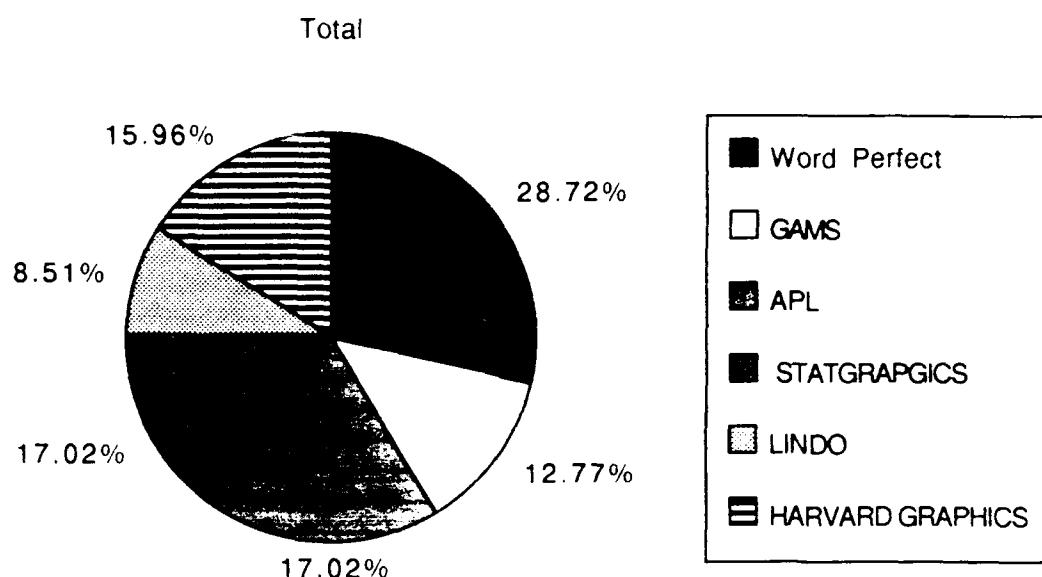


Figure 4.1 Software Usage Percentage At OR-PC Laboratory³

³ Data source: Survey issued to sixth and eighth quarter OA students in February 1990, sample size : 82.

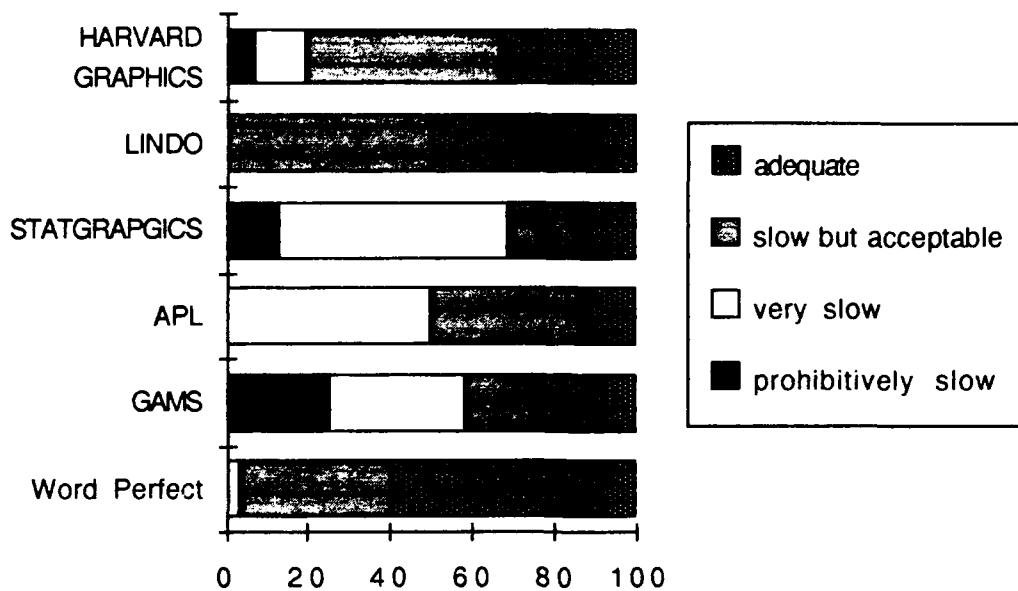


Figure 4.2 Analysis Of User Satisfaction Degree For Each Software⁴

The cost of the more powerful 32-bit 386 machine is currently decreasing, bringing its price closer to that of PC-AT or PC-XT (its function is similar to PC-AT). Thus, the 16-bit Zenith Z-248 PC-AT computer could be replaced and the needs of students be met at a relatively low cost.

⁴ Data source is same as Figure 4.1. Responses regarding speed: "slow but acceptable", "very slow", or "prohibitively slow" shown by ratios (0% to 100%): WORDPERFECT 40.70%, GAMS 75%, LINDO 50%, HARVARD GRAPHICS 66.66%, APL and STAGRAPHICS are the highest at 87.5%.

B. COST-EFFECTIVENESS ANALYSIS

1. Introduction

Cost-effectiveness analysis is an analytical concept or procedure. A set of ordered steps can be followed in the development of a system or product. It is an outgrowth of the research program of the RAND corporation and similar organizations in the field of defense research. Even though this research program is about fifty years old, cost-effectiveness is conceptually derived from operations research, and the original may be traced back to the beginning of WORLD WAR II. It is a systematic study designed to assist decision makers in identifying a preferred choice among possible alternatives. In addition, cost-effectiveness relates to the measure of a system in terms of mission accomplishment by system-effectiveness and cost measurement by life-cycle-cost (L.C.C). [Ref.10 p.v]

2. Cost-Effectiveness Analysis Vs. Cost-Benefit Analysis

Broadly, cost-effectiveness analysis is similar to the standard cost-benefit analysis which is employed for decision making. As Rodney D. Stewart & Richard M. Wyskida "*Cost estimator's Reference manual*" states:

- . **Cost-Benefit Analysis.** A technique for assessing the range of costs and benefits associated with a given option to determine feasibility in monetary terms.
- . **Cost-Effectiveness Analysis.** An analytical approach to solving problems of choice. It requires (1) the definition of objectives, (2) identification of alternatives ways of achieving each objectiveness, and (3) the identification for each objectives or alternative that yield the

required level of benefits at the lowest cost when the benefit of the alternatives cannot be quantified in terms of dollars.

[Ref. 11: p.560 & p.569].

From the previous definitions, both analysis methods are used to determine the input cost and output benefit for each alternative. However, the cost-benefit analysis method usually determines the cost and benefit in terms of monetary values. The cost-effectiveness method may measure the cost in dollars and uses qualification scale to estimate the benefit for system-effectiveness for benefit that cannot be easily quantified in terms of dollars.

The following Table 4.1 shows the comparison of two analysis method.

Method	Cost-Benefit analysis	Cost-Effectiveness analysis
Similarity	(a) A systematic approach to estimate cost and benefit among each alternative (b) A decision making aid for decision makers	Same as cost-benefit analysis
Difference	Normally determine the cost and benefit in terms of monetary values	Estimate benefit for system effectiveness which does not exist in terms of monetary value.

Table 4.1 The Comparison Of Cost-Benefit Analysis And Cost-Effectiveness Analysis

Because this thesis will analyze the costs and the non-monetary system-effectiveness of each alternative, the cost-effectiveness analysis is adopted.

3. Cost-Effectiveness Analysis Structure

Figure 4.3, "Process of cost-effectiveness analysis", shows the structure of cost-effectiveness analysis and Figure 4.4, "The ingredients of cost-effectiveness analysis", illustrates the main elements of L.C.C analysis and system-effectiveness analysis.

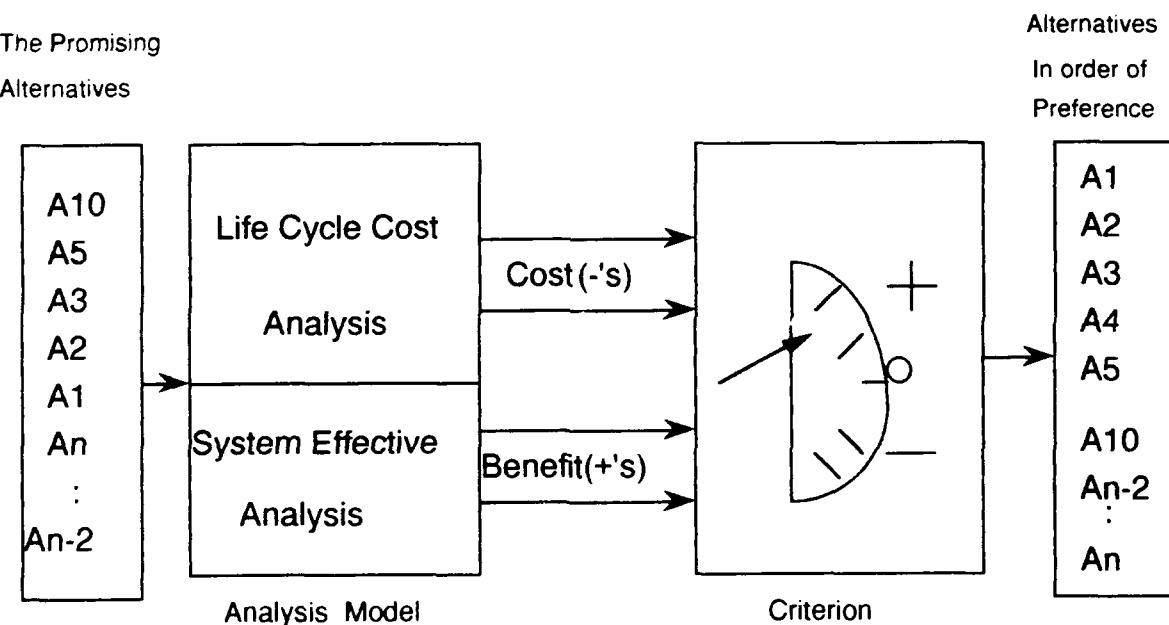


Figure 4.3 The Process Of Cost-Effectiveness Analysis

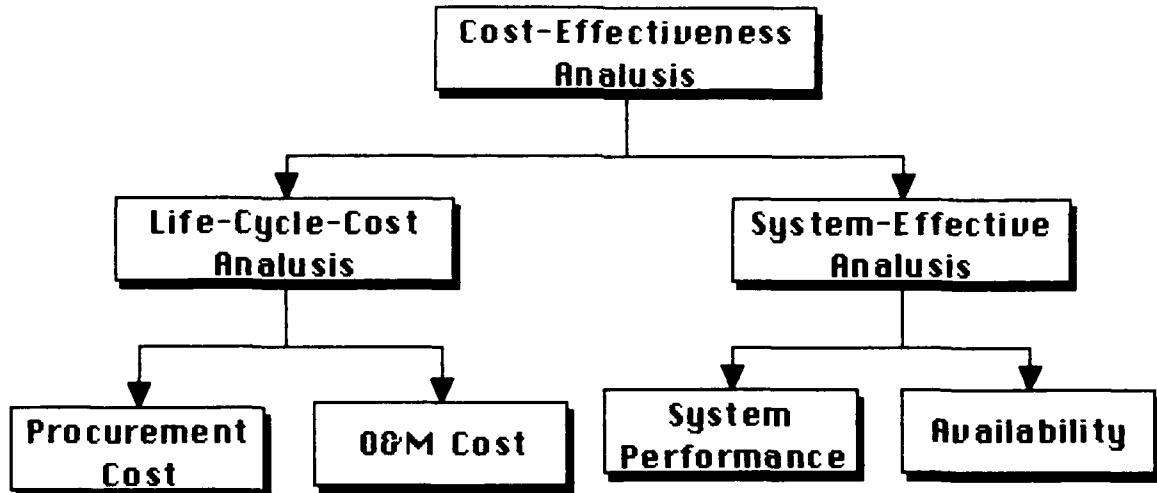


Figure 4.4 The Ingredients Of Cost-Effectiveness Analysis⁵

Two analysis methods are used to decide the cost and benefit of each alternative. L.C.C. analysis is used to determine cost and System-Effectiveness analysis is used to measure benefit. Both methods will be addressed in detail in later paragraphs. The non-monetary type system-effectiveness of each alternative will be analyzed here. Therefore, the cost effectiveness analysis will be applied.

4. Life Cycle Cost (L.C.C) Analysis

a. *Introduction*

Life-cycle cost analysis is a systematic analysis which includes all costs associated with the system life cycle. Generally, it involves three categories:

⁵ Normally, the OR-PC laboratory upgrading plan does not involve R&D cost for new system design and development. For system-effectiveness analysis, operability (measure of simplicity of operation), operational suitability (measure of user satisfaction), and the safety measurement are important, but it is hard to collect the comparative data to treat them, so the discussion of system performance and availability will be emphasized.

(1). Research and development (R&D) cost: The costs associated with the development of a new system (e.g., system analysis, system design, detailed design and development and initial system test evaluation, etc.)

(2). Investment/procurement cost: This is one-time, non-recurring cost which is required to introduce the capability into the operational inventory.

(3). Operations and maintenance (O&M) cost: The cost of sustaining system operation and maintenance support. This is a recurring cost which is required year by year to operate and maintain the system capability over a time period.

Figure 4.5 shows the relationship of these costs in the life of a general system [Ref. 13: P.104].

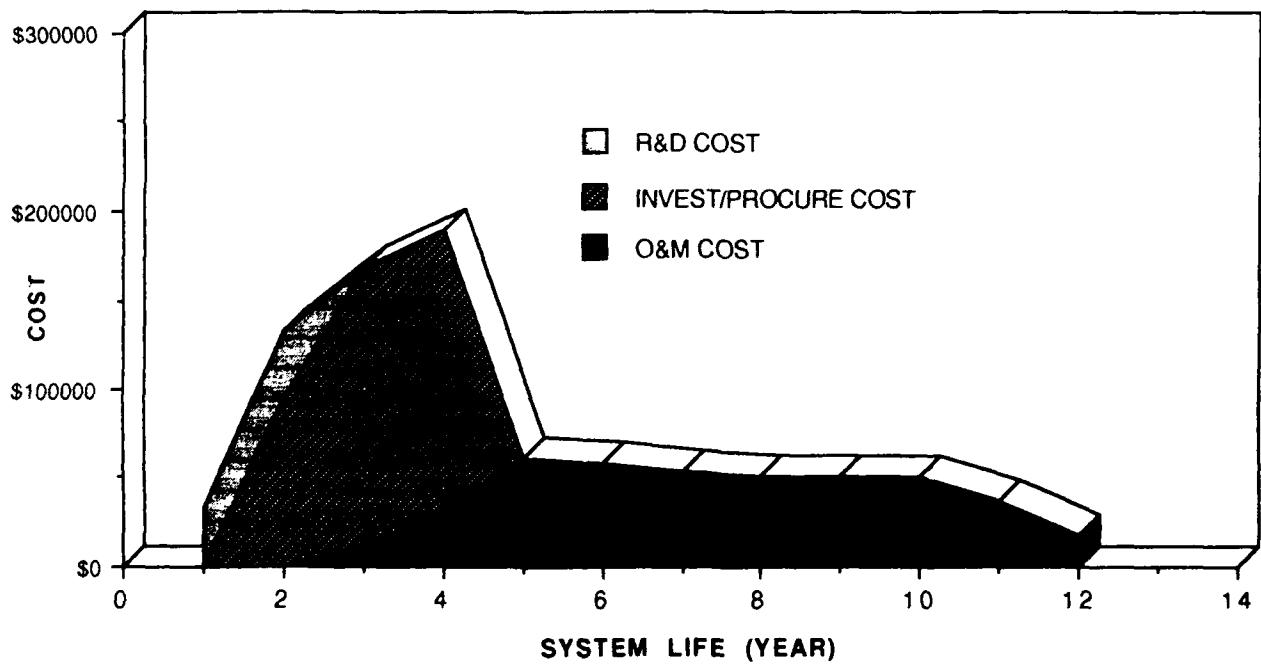


Figure 4.5 An Example Of L.C.C. Depiction Of A System

This study does not include the R&D cost and assumes the maintenance cost per year to be constant, thus the cost structure may be viewed as shown in Figure 4.6.

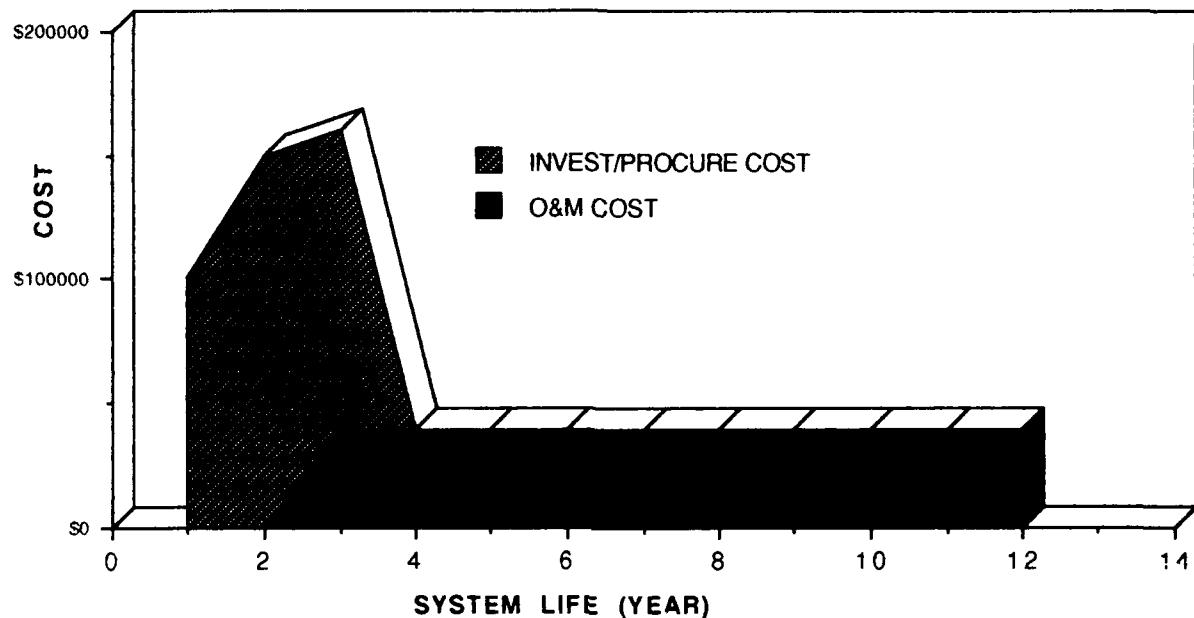


Figure 4.6 A L.C.C. Depiction Of A System With Annual Constant O&M Cost

b. Economic Life Discussion And Assumption

The economic life of an asset is defined as a reasonable period of time over which an economic analysis can be applied to each alternative. The economic analysis should start from the same base-year, i.e., project year-1 to the end of the project life. The economic life is based on the assumption that each project has a limited life over which the mission can be accomplished. Normally, the economic life will be decided by one of following three factors:

(1). The mission life: the period over which a need for the assets or program is anticipated. For example, a junior level college student decides to purchase a used IBM PC compatible to do his assignments at home. He assumes that he will need this computer only until graduation. After his studies are completed he will have enough money to buy a new one. Thus, the mission life of this IBM PC compatible is about two years.

(2). The physical life: the period over which the asset, for example a facility or a piece of equipment like a computer hardware, is available for use until it wears out physically.

(3). The technological life: the period over which an asset can be used before the improved technology renders the asset obsolete or inefficient. Because of rapidly changing technology, a computer system has to be upgraded regularly.

Generally, the economic life will be the shortest of the above three factors. In this thesis, it is assumed that computer technological life is at most five years and is treated as the economic life. Therefore, after five years the hardware of OR PC laboratory may be upgraded again. [Ref.8: p.7.1]

c. Cash Flow Diagram

In economic analysis, a cash flow diagram is used to illustrate the cost allocation of each alternative. A graphic technique with a horizontal time line, it is drawn chronologically and is divided by the time period of the economic life. Figure 4.7 shows a typical cash flow for an alternative with a five year economic life. A cash flow diagram will be drawn for each alternative later.

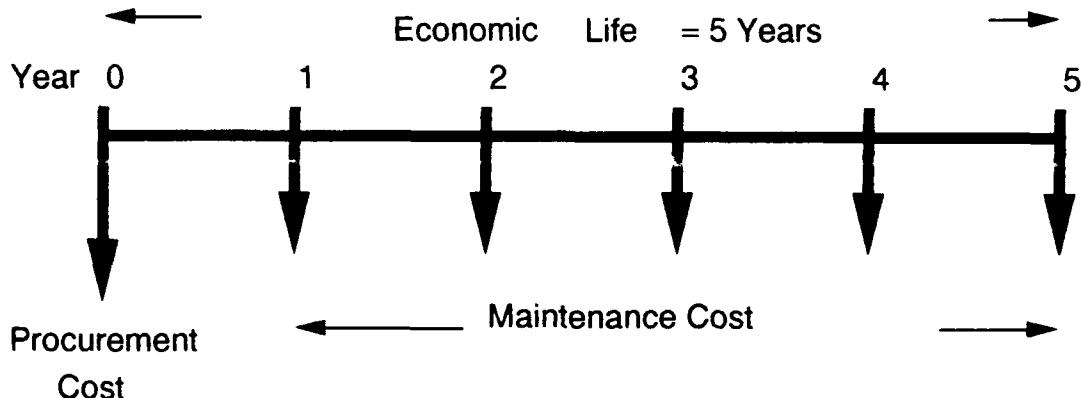


Figure 4.7 A Standard Cash Flow Diagram⁶

d. Present Value (P.V)

In Life Cycle-Cost (L.C.C.) analysis, the time value of money with regards to present value must be considered. Generally, the DOD applies a standard 10% discount rate to deal with present-value and this rate is used here for further analysis.

Table 4.2, "The present value of different project year" shows the time-adjusted present value dollars, are based on the present value of \$1.00 starting from project initialization-procurement at year zero.

⁶ Usually a new computer system has one year warranty (from year zero to year one) so the maintenance cost will not compute until year one.

Year	Present Value Under 10% Discount (interest) Rate	Cumulative
1	0.954	0.954
2	0.867	1.821
3	0.788	2.609
4	0.717	3.326
5	0.652	3.977
6	0.592	4.570
7	0.538	5.108
8	0.489	5.597
9	0.445	6.042
10	0.405	6.447
:	:	:
n	$\frac{1}{(1+i)^{\frac{n-1}{2}}}$	$\sum_{i=1}^n \frac{1}{(1+i)^{\frac{n-1}{2}}}$

Table 4.2 The Present Value Of Different Project Year

Basically, the formula in Equation 4.1 calculates a mid-year present value. Calculation are shown in Figure 4.8.

$$P.U. = \frac{1}{(1+i)^{\frac{n-1}{2}}} \quad (\text{Equation 4.1})$$

P.U. : Present Value

i : Interest rate or Discount rate = 10%

n : Project in the Nth Year, n=1,2,3 ...

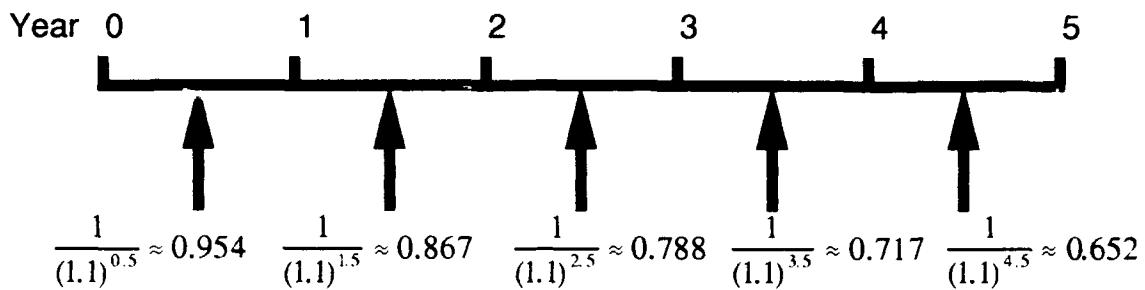


Figure 4.8 The Computation Of Mid-year 10% Discounted Present Value

e. Cost Breakdown Structure (C.B.S.) In Terms Of Cost Model

The cost breakdown structure (C.B.S.), also known as a cost-tree or cost-element structure, is a hierarchical division of cost by function and major items. When applying this concept to life-cycle cost analysis, a cost breakdown structure will show the numerous categories which are combined to provide the total cost. Generally, the cost breakdown structure should include the following characteristics:

(1). All the system elements during the system life cycle (five years) must be considered.

(2). Cost elements must be clearly defined, so that the decision makers, budgeteers and program managers can understand what is included in the cost categories and what is not. One has to be careful to prevent missing or double counting costs. An inadequate definition may cause inconsistencies in the economic analysis process and can lead to a wrong decision.

Figure 4.9 shows an example of cost breakdown structure. Accordingly, costs can be accumulated at the different levels depending on the interested area and the required depth.

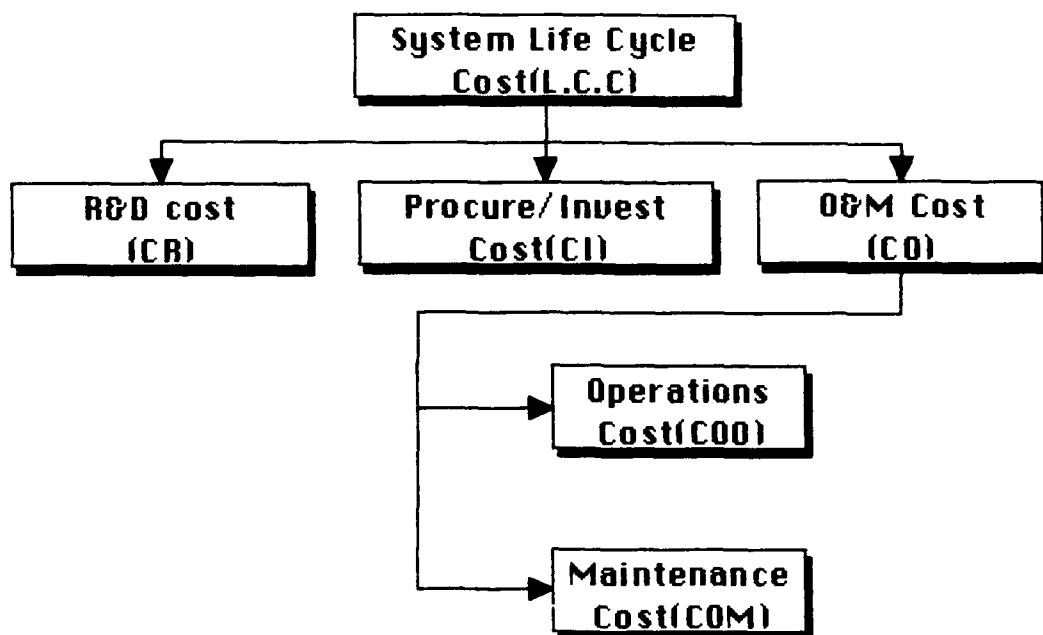


Figure 4.9 An Example Of Cost Breakdown Structure

Cost breakdown structure can be described in terms of small cost models for computing the particular cost. Table 4.3 illustrates a cost breakdown structure with regards to cost category, mathematical equation, and description. [Ref. 13: pp. 373-390]

Cost Category (Refer to Figure 4.9)	Mathematical equation	Descriptions
Life Cycle Cost (L.C.C.)	$L.C.C. = [CR+CI+CO]$ <p>CR: R & D Cost CI: Investment or Procurement cost CO: Operations and Maintenance cost</p>	Includes all future cost associated with the acquisition, utilization and the maintenance requirements of the system.
Operation and Maintenance Cost (CO)	$CO = [COO+COM]$ <p>COO: Cost of system life cycle operations COM: Cost of system life cycle maintenance</p>	Includes all costs associated with the operation and maintenance support of the system through its life cycle. The costs will be accounted for each year through the system life cycle

Table 4.3 An Example Of Cost Category⁷

f. Compare And Plot Of L.C.C For Each Alternative

(1). Plot of Cash Flow Diagram

The cash flow diagrams of each alternative are illustrated as Figures 4.10, 4.11 and 4.12.

⁷ In thesis the R&D cost is not computed. The R&D cost can only be assigned for the cost which is related to the new system design and development.

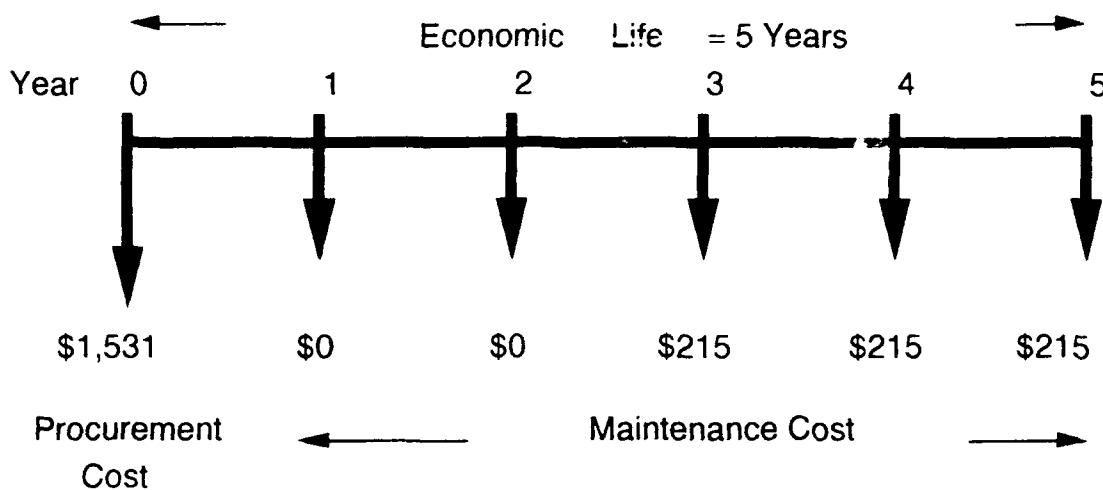


Figure 4.10 The Cash Flow Diagram For UNISYS System⁸

The non-recurring procurement cost for UNISYS system is \$1,531 [Ref 14: p.16]. Because this system has a two year warranty, the operations and maintenance (O&M) cost is computed from year three. The annual price is \$215 [Ref 15 & 16: Table 1b p.2].

⁸ This diagram shows the undiscounted cash flow. Actually it shows the cost of each year (flow sign " \downarrow "). The present value in Figure 4.8 is calculated of "mid-year" (flow sign " \uparrow ") and it is recorded for each year (until " \downarrow " exist). The computations are based on only one unit computer. The other two Figures, 4.11 and 4.12 have the same situation. [Ref. 8: Pp.7.1-7.8]

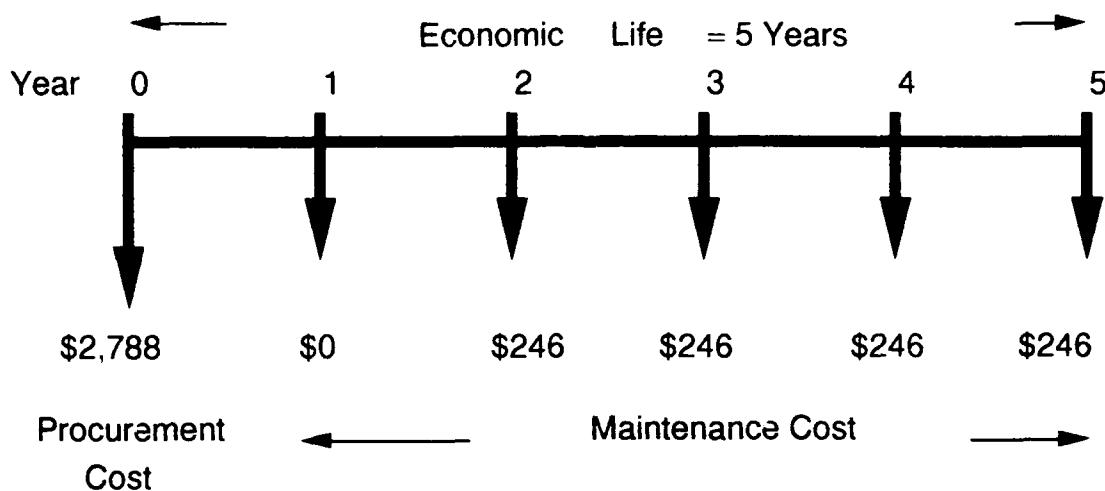


Figure 4.11 The Cash Flow Diagram For Upgraded Zenith System

The non-recurring procurement cost for upgraded Zenith system is \$2,788 (\$1,950 for CPU board, \$239 for Z-549, VGA video card, \$549 for ZCM-1490-Z, VGA monitor). [Ref. 17: p. 3 & Ref. 18: pp. 34-35].

The recurring O&M cost is \$246 per year (CPU board \$199; VGA video card \$36. VGA monitor \$11). Because the AMI and Zenith corporations only support a one year warranty, the O&M cost will be computed from year two.

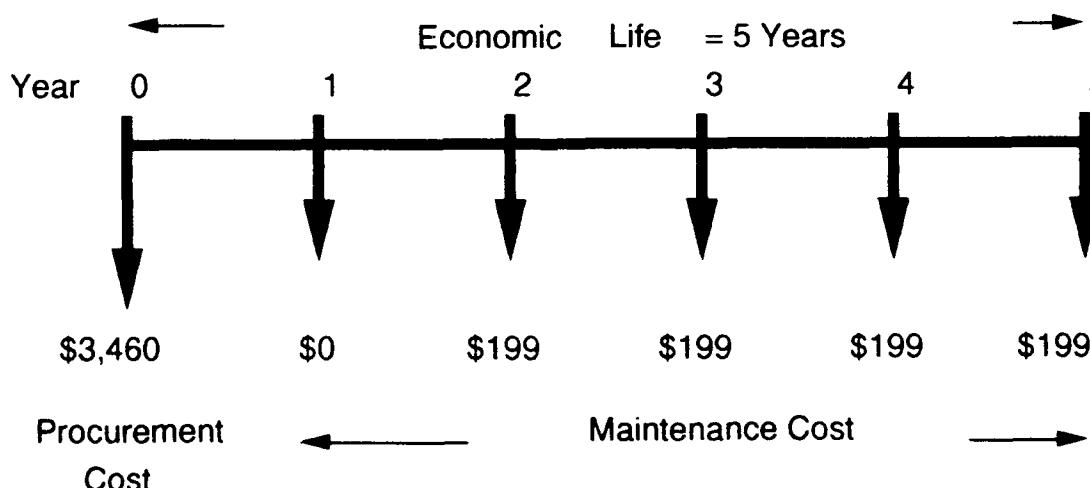


Figure 4.12 The Cash Flow Diagram For DELL-310 System

The non-recurring procurement cost for DELL-310 system is \$3,460. The recurring O&M cost from XEROX service with the system is \$199 per year. DELL and XEROX corporations only support one year warranty. The O&M cost will be computed from year two [Ref. 19 & Ref. 20].

(2). Plot Of Discounted and Undiscounted L.C.C.

(a). The UNISYS System

The undiscounted and 10% discounted L.C.C. for UNISYS system are shown in Table 4.4. They are \$2,176 and \$1,994.755 respectively. The relevant graphics are illustrated in Figure 4.13 and 4.14.

Year	Undiscounted Cost	Undiscounted Cumulative Cost	P.V. of 10% Discounted Cost	Discounted Cost	Discounted Cumulative Cost
0	\$1,531.000	\$1,531.000	1.000	\$1,531.000	\$1,531.000
1	\$0.000	\$1,531.000	0.954	\$0.000	\$1,531.000
2	\$0.000	\$1,531.000	0.867	\$0.000	\$1,531.000
3	\$215.000	\$1,746.000	0.788	\$169.420	\$1,700.420
4	\$215.000	\$1,961.000	0.717	\$154.155	\$1,854.575
5	\$215.000	\$2,176.000	0.652	\$140.180	\$1,994.755

Table 4.4 The Undiscounted And Discounted L.C.C. Of UNISYS System

PLOT OF UNISYS SYSTEM L.C.C. (UNDISCOUNTED)

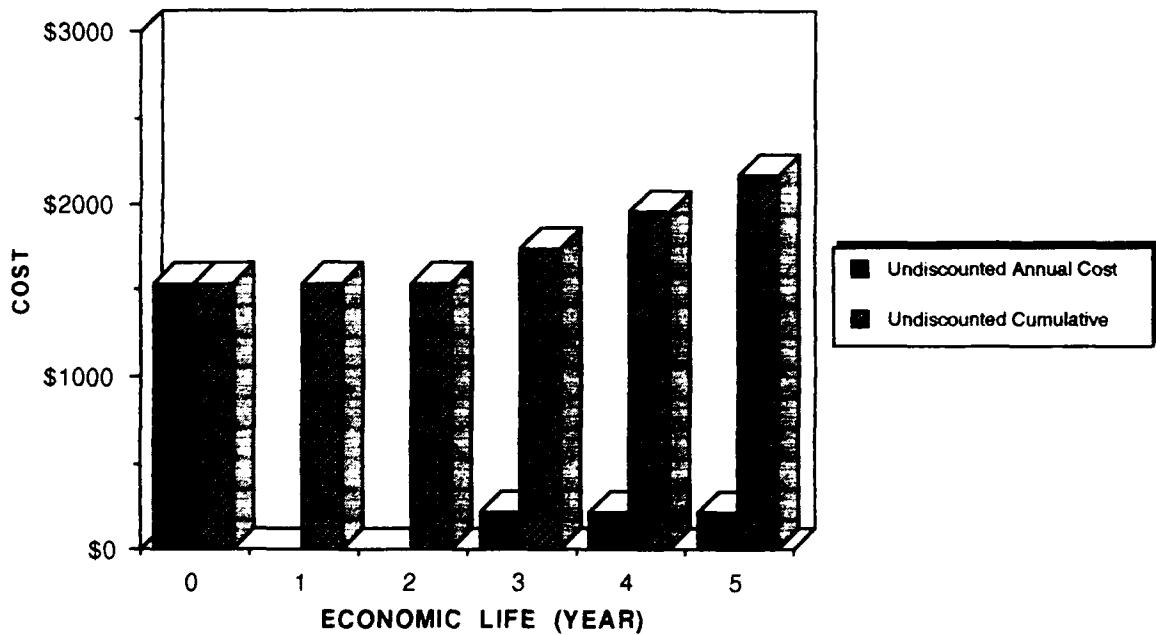


Figure 4.13 The Graphic Of Undiscounted L.C.C. Of UNISYS System

PLOT OF UNISYS SYSTEM L.C.C. (DISCOUNTED)

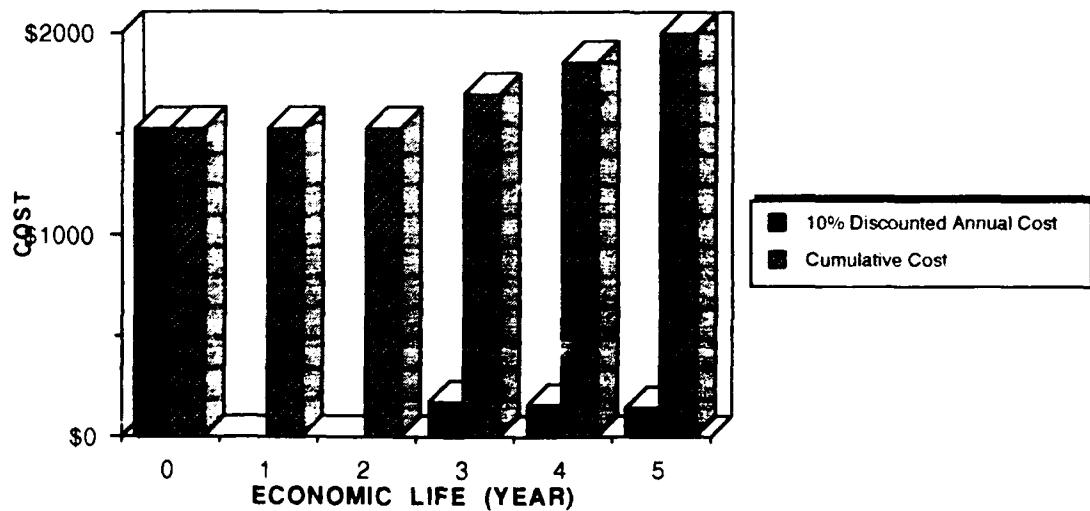


Figure 4.14 The Graphic Of 10% Discounted L.C.C. Of UNISYS System

(b). The Upgraded Zenith System

Table 4.5 shows the undiscounted L.C.C. for upgraded Zenith system to be \$3,772. The 10% discounted L.C.C. is \$3,531.904. The relevant graphics are illustrated in Figure 4.15 and 4.16.

Year	Undiscounted Cost	Undiscounted Cumulative Cost	P.V. of 10% Discounted Cost	Discounted Cost	Discounted Cumulative Cost
0	\$2,788.000	\$2,788.000	1.000	\$2,788.000	\$2,788.000
1	\$0.000	\$2,788.000	0.954	\$0.000	\$2,788.000
2	\$246.000	\$3,034.000	0.867	\$213.282	\$3,001.282
3	\$246.000	\$3,280.000	0.788	\$193.848	\$3,195.130
4	\$246.000	\$3,526.000	0.717	\$176.382	\$3,371.512
5	\$246.000	\$3,772.000	0.652	\$160.392	\$3,531.904

Table 4.5 The Undiscounted And Discounted L.C.C. Of Upgraded Zenith System

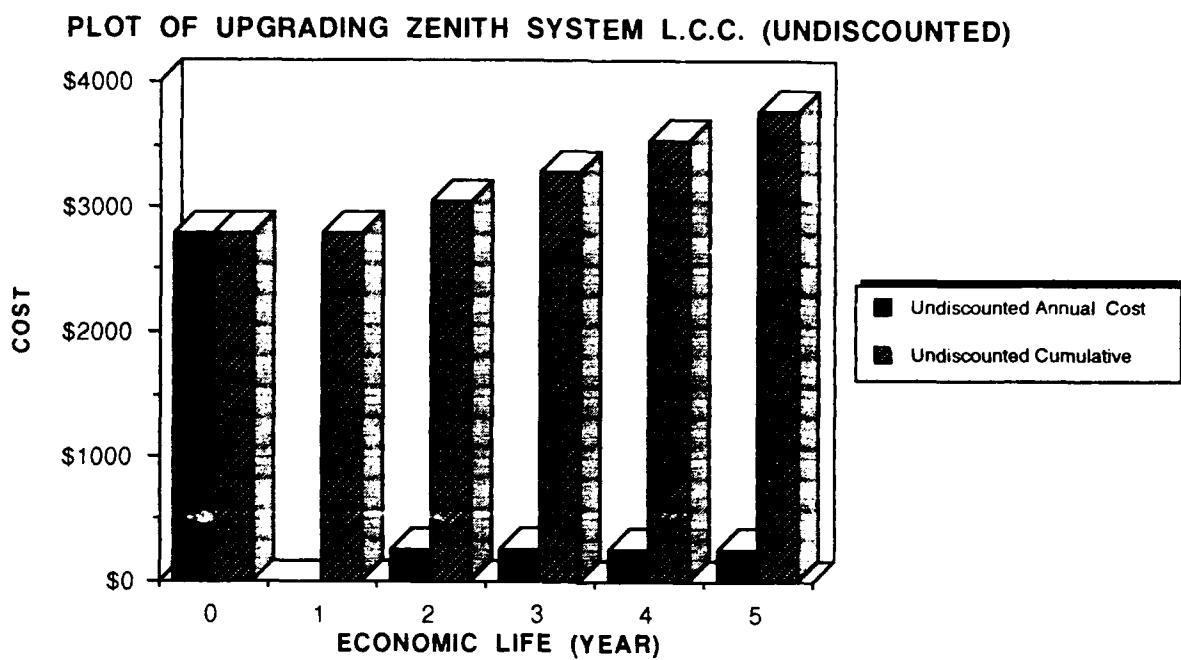


Figure 4.15 The Graphic Of Undiscounted L.C.C. of Upgraded Zenith System

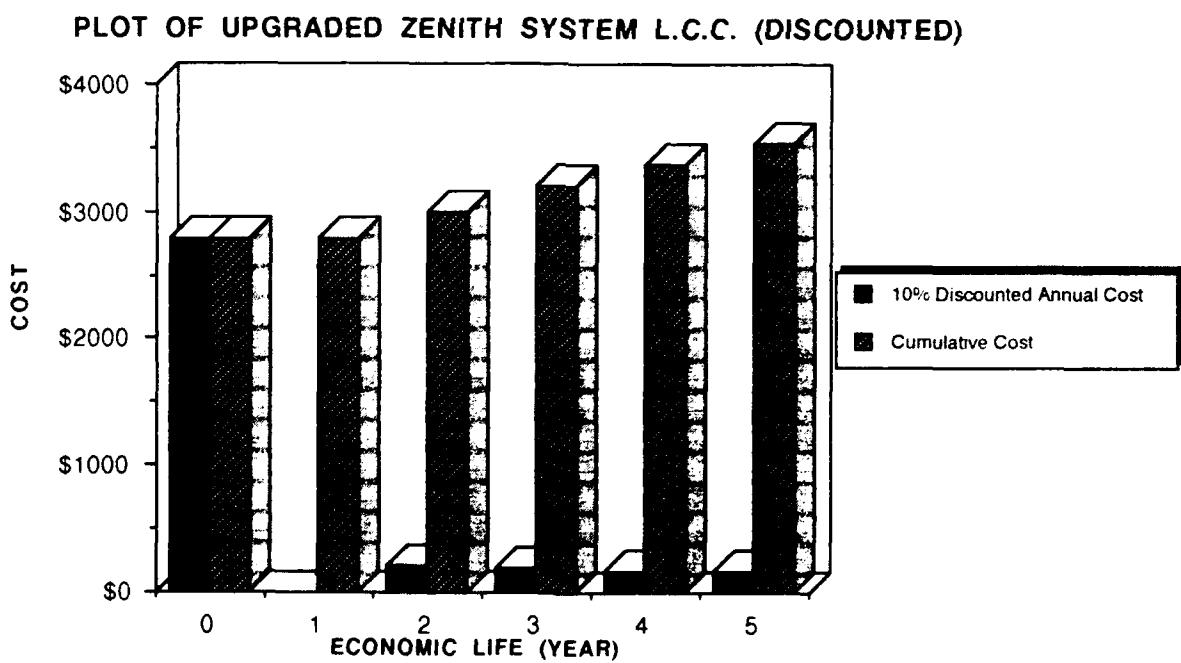


Figure 4.16 The Graphic Of 10% Discounted L.C.C. Of Upgraded Zenith System

(c). The DELL-310 System

Table 4.6 shows the undiscounted L.C.C. for the DELL-310 system to be \$4.256. The 10% discount L.C.C. is \$4.061.776. The graphics are illustrated in Figure 4.17 and 4.18.

Year	Undiscounted Cost	Undiscounted Cumulative Cost	P.V. of 10% Discounted Cost	Discounted Cost	Discounted Cumulative Cost
0	\$3,460.000	\$3,460.000	1.000	\$3460.000	\$3,460.000
1	\$0.000	\$3,460.000	0.954	\$0.000	\$3,460.000
2	\$199.000	\$3,659.000	0.867	\$172.533	\$3,632.533
3	\$199.000	\$3,858.000	0.788	\$156.812	\$3,789.345
4	\$199.000	\$4,057.000	0.717	\$142.683	\$3,932.028
5	\$199.000	\$4.256.000	0.652	\$129.748	\$4,061.776

Table 4.6 The Undiscounted And discounted L.C.C. Of DELL-310 System

PLOT OF DELL-310 SYSTEM L.C.C. (UNDISCOUNTED)

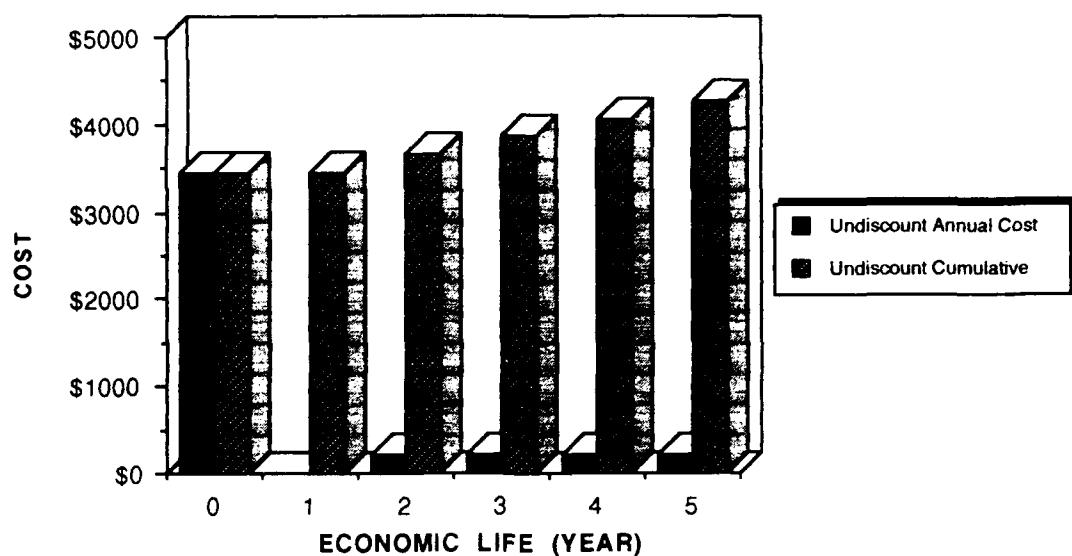


Figure 4.17 The Graphic Of Undiscounted L.C.C. Of DELL-310 System

PLOT OF DELL-310 SYSTEM L.C.C. (DISCOUNTED)

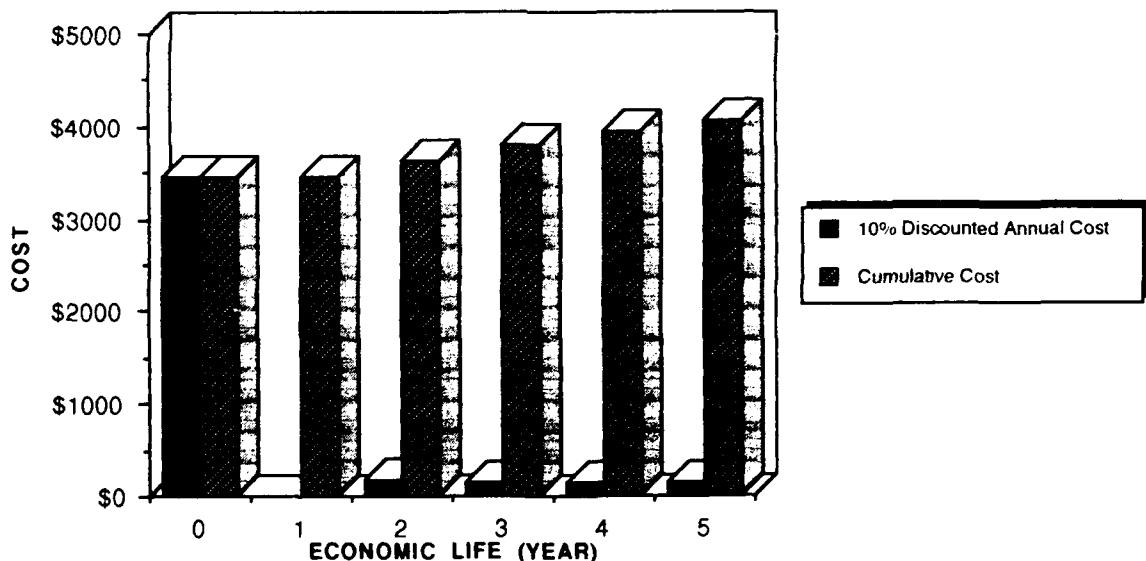


Figure 4.18 The Graphic Of 10% Discounted L.C.C. Of DELL-310 System

(d). L.C.C. Comparison for each alternative

The L.C.C. comparison of three alternatives is illustrated in Figures 4.19 and 4.20. It seems that the undiscounted and 10% discounted L.C.C. of the UNISYS system is cheaper than that of upgraded Zenith and DELL-310 system. The undiscounted cost are \$2,176 for UNISYS, \$3,772 for the upgraded Zenith and \$4,256 for DELL-310. The discounted cost are \$1,994.755, \$3,531.904 and \$4,061.776, respectively.

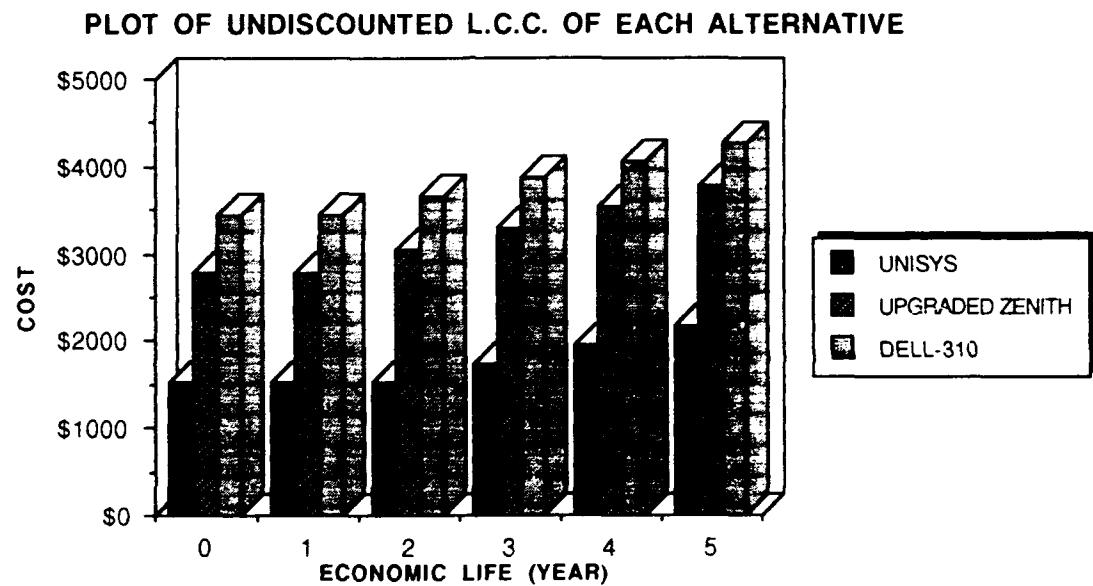


Figure 4.19 The Graphic Of Undiscounted L.C.C. Of Each Alternative

PLOT OF 10% DISCOUNTED L.C.C. OF EACH ALTERNATIVE

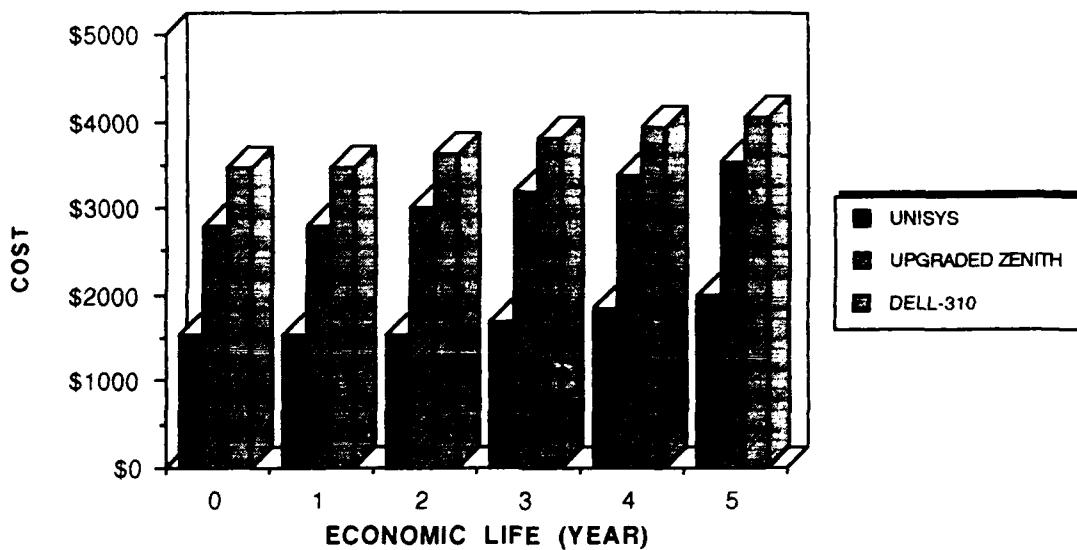


Figure 4.20 The Graphic Of 10% Discounted L.C.C. Of Each Alternative

5. System-Effectiveness Analysis

a. *Benefit Quantification*

The system-effectiveness analysis is a method to measure the non-monetary type benefit. Benjamin S. Blanchard in "*Logistics Engineering And Management*" points out that effectiveness must consider:

- (1). System performance and physical parameters - capacity, range, accuracy, volume, speed, weight and so on.
- (2). System operational and support factors - availability, reliability, maintainability, supportability. [Ref 13: p.77].

As in the previous discussion, the system effectiveness comparison of each alternative can be quantified as follows:

(1). System performance: The system performance is a major component of system effectiveness. It determines whether the system performs efficiently. It can be measured by capacity, speed, accuracy and the amount of paper produced by a computer system. These parameters will be emphasized for each alternative.

(2). System availability in terms of maintainability and supportability: Availability is defined as a measure of system readiness that "determines the degree, percent or probability that a system will be ready or available when required for use" Ref. 13: p. 64]. There are three different kinds of availability: inherent, achieved and operational. The operational availability is the most widely used. Mathematically, it is expressed as:

$$R_o = \frac{MTBM}{MTBM + MDT} \quad \text{(Equation 4.2)}$$

Where MTBM is the mean time between maintenance and MDT is the Mean Down Time. Therefore, the operational availability depends on the maintainability and supportability-including the technical, personnel and repair part support.

The operational availability is one of the major measurements for a system. In this thesis, the maintainability and supportability of each alternative will be qualitatively addressed. However, because the failure rate (λ [which determines the reliability of each system]) is unknown, it is not addressed. The OR PC laboratory record from 1987 to 1989 shows only one malfunction.

b. Comparison Of System-Effectiveness For Each Alternative

(1). Comparison of System Performance

The comparison of system performance for each alternative in this case is based on two different factors: harddisk capacity (or harddisk storage) and math-coprocessor. The harddisk capacity is an important component of a system. A high harddisk capacity allows more application software and data to be stored and utilized. Furthermore, if the harddisk capacity of the system is too small, application software, e.g., graphic processor, which need a lot of disk storage as data buffer and system buffer cannot be loaded. The limitations of the system software package will restrict the usage of users. From the collected data, the UNISYS system has 42MB harddisk capacity, slightly more than that of DELL-310 system (40MB), and about twice that of the upgraded ZENITH system (20MB). Even though the existing six software packages: WORDPERFECT, STATGRAPHIC, GAMS, APL, LINDO and HARVARD GRAPHICS can work in a 20 MB upgraded Zenith system, the 20 MB environment will limit new applications from being introduced.

A scaling method is used here to determine the relative scale of harddisk capacity for each alternative. Equation 4.3 shows an example of this approach. The calculation formula is:

$$S_A = \frac{C_A}{C_B} \quad (\text{Equation 4.3})$$

S_A : Relative scale of system-A capacity

C_A and C_B : The capacity of system-A & the lowest system-B (as a base line)

The scale shows the degree of importance: a higher scale means a higher relative importance of a system. For example, if the 20 MB upgraded Zenith system is set at benchmark scale 1.0, the relative scale of UNISYS system based on harddisk capacity will be the ratio of 42MB/20MB X 1.0, therefore the scale is 2.1. To use a similar calculation for the DELL-310 system, the scale will be 2.0 (40MB/20M X 1.0). These scales assume there is no decrease in the utility of additional storage. Although this is extreme, only a very simple approach is needed here.

The math-coprocessor is a "speed driver" of a system. When executing a complex calculation, the math-coprocessor is required. From the collected data, each alternative supports a math-coprocessor for computation: the UNISYS system and DELL-310 system support the Intel 80387 math-coprocessor; the Zenith upgraded system supports the existing Intel 80287 math-coprocessor. Note that the 80387 math-coprocessor is an improvement over the 80287 math-coprocessor. Furthermore, the 80387 math-coprocessor provides the system with significant enhancements in operation and speed over the 80287 math-coprocessor. Laboratory test results show the 80387 takes fewer clocks per instruction than the 80287 because of the new instruction added to 80387 and the expended operand range.

Table 4.7 shows the new instructions added to the 80387 coprocessor instruction set. [Ref. 2 :pp. 207-215].

Instruction	Function
FCOS	Cosine
FSIN	Sine
FSINCOS	Sine And Cosine
FUCOM	Unordered Compare Real
FUCOMP	Unordered Compare Real & Pop Stack
FUCOMPP	Unordered Compare Real & Pop Twice
FPREMI	IEEE Standard Partial Remainder

Table 4.7 The New Instructions Added To The 80387 Instruction Set

FCOS, FSIN, FSINCOS are trigometric instructions; FUCOM, FUCOMP, FUCOMPP are unordered compare instructions; FPRIMI is an IEEE remainder instruction.

(a). Trigonometric Instruction

The instruction FCOS computes the cosine of the contents of ST (stack) and replaces it with COS(ST): FSIN instruction is similar to FCOS, it computes the sine of the contents of ST and replace it in SIN(ST): FSINCOS instruction computes both the sin and consine of the contents of ST. First, the contents of ST are replaced by SIN(ST), and then COS(ST) is pushed onto the ST.

(b). Unordered Compare Instructions

The FUCOM, FUCOMP and FUCOMPP are three new instructions in the 80387 math-coprocessor to perform unordered comparisons. They are used to compare the value on top of the stack to the source operand, where the source operand can be in "unordered type": a register or on stack, or single- or double-memory operand. After the comparison, a true (If the value of stack is

larger) or false condition will be given then the FUCOM instruction will not pop the stack, but FUCOMP will pop once and FUCOMPP will pop the stack twice.

(c). IEEE 754-Compatible Remainder Instruction

FPRIMI is a IEEE compatible remainder instruction. It computes the remainder of the division of ST by ST(1) and result is stored in ST. The Equation 4.4 shows the formula:

$$r = ST - ST(1) \cdot q \quad (\text{Equation 4.4})$$

r: a remainder

q: an integer

ST: a 80-bit temporary storage

ST(i) : a set of eight 80-bits general purpose register with $i = 0, 1, 2, \dots$

ST(1) Is the second register of ST(i)

The following Table 4.8 illustrates the 80387 has extended the operand range of four instruction: FPTAN, FPATAN, F2XM1 and FSACLE.

Instruction	Function	80387 Operand Range	80287 Operand Range
FPTAN	Partial Tangent	$ ST(0) < 2^{63}$	$ ST(0) < \frac{\pi}{4}$
FPATAN	Arctangent	Unrestricted	$ ST(0) < ST(1) $
F2XM1	$2^x - 1$	$-1 \leq ST(0) \leq 1$	$0 \leq ST(0) \leq 0.5$
FSACLE	Scale	Unrestricted	Undefined in $0 < ST(1) < 1$

Table 4.8 The Comparison Of 80387 And 80287 Operand Range

FPTAN, FPATAN, F2XM1 and FCALE are the four expanded range instructions contained in the 80387 math-coprocessor. The FPTAN instruction computes the tangent function $Y = \text{TAN}(ST)$; the FPATAN instruction compute the arctangent function $\theta = \text{Arctan}(Y/X)$ where X and Y indicate the contents of ST(0) and ST(1); the F2XM2 instruction computes the function $Y = 2^H - 1$, $-1 \leq H \leq 1$; the FSCALE instruction scales the top of stack-ST(0) by the power of 2 given in ST(1), where the contents of ST(1) are unrestricted.

Usually the OR software involves a lot of calculations, e.g., simulation, so the math-coprocessor is very important for OR-PC laboratory. Furthermore, if the system is upgraded to 80386 level, the 80387 math-coprocessor should be required and the 80287 math-coprocessor will not be adopted again. But in order to compare the system performance of original alternatives, the slower speed 80287 math-coprocessor will be treated here. The impact of replacing 80287 math-coprocessor will be addressed later.

Because of the lack of real speed comparison between 80287 math-coprocessor and 80387 math-coprocessor, the previous scaling method is not appropriate here. But for objective, the 80287 math-coprocessor can be treated as bench mark scale 1.0, and the relative scale of higher speed 80387 math-coprocessor will be $1.0 + \omega$, where ω is a ratio of speed and $\omega \geq 0$. The total scale of three original alternatives comparing system performance is then addressed in the Table 4.9.

Weighing Item	UNISYS (Scale)	Upgraded Zenith (Scale)	DELL-310 (Scale)
1. Harddisk Capacity	4 MB (2.1) (Relative scale)	20 MB (1.0) (benchmark scale)	40 MB (2.0) (relative scale)
2. Math Coprocessor	Original: 80387 (1.0 + ω) (Relative scale)	Original: 80287 (1.0) (benchmark scale)	Original: 80387 (1.0 + ω) (Relative scale)
Total Scales	$3.1 + \omega$	2.0	$3.0 + \omega$

Table 4.9 The Comparison Of System Performance By Scaling Method

It seems that the scale $3.1 + \omega$ of UNISYS system from system performance view is better than 2.0 of upgraded Zenith system and $3.0 + \omega$ of DELL-310 system. However, there is very little difference between $3.1 + \omega$ and $3.0 + \omega$.

(2). Comparison of System Availability

As stated in previous statements, only the maintainability and supportability are discussed here. The maintainability is determined by the supportability of technique, personnel, repair part and documentation. Table 4.10 shows the maintenance information of each alternative.

Item	UNISYS System	Upgraded Zenith System	DELL-310 System
Maintenance corporation	UNISYS Only	Zenith/AMI	DELL/XEROX
Maintenance type	UNISYS takes care of the maintenance of total system.	AMI only in charge of the maintenance of new CPU board, Zenith takes care of the others.	DELL has contract with XEROX and XEROX in charge of all system's maintenance.
GSA Contract (Yes/No)	Yes	Yes	Yes

Table 4.10 The Maintenance Information Of Each Alternative

Table 4.10 shows no significant difference of maintainability and supportability between each alternative, therefore, the maintainability and supportability should be same.

Normally, the system availability is as important as the system performance. The former will assure a system is in working condition, the latter will guarantee the system to work effectively. The assumption is made that both have the same "weight" of importance. Therefore, a scale is assigned to two different measurements of "System-Performance", i.e., the harddisk capacity and speed of math-coprocessor, for the one measurement of "System performance" (actually itself and it is in terms of maintainability/supportability) , the scale should be counted twice, i.e., 1.0 becomes 2.0, 1.5 becomes 3.0 etc.

The result of Table 4.11 shows UNISYS system has highest scale of $5.1 + \omega$ for system-effectiveness, slightly higher than $5.0 + \omega$ of DELL-310 system and significantly over 4.0 of the upgraded Zenith system.

Measuring System Effectiveness	UNISYS (Scale)	Upgraded Zenith (Scale)	DELL-310 (Scale)
1. System Performance: (a). Harddisk Capacity	42 MB (2.1)	20 MB (1.0)	40 MB (2.0)
(b). Mathematics coprocessor	Original: 80387 ($1.0 + \omega$)	Original: 80287 (1.0)	Original: 80387 ($1.0 + \omega$)
2. System Availability : maintainability and supportability	Same (1.0×2)	Same (1.0×2)	Same (1.0×2)
Total Scales	$5.1 + \omega$	4.0	$5.0 + \omega$

Table 4.11 The Comparison Of System-Effectiveness By Scaling Method

6. Combination comparison Of L.C.C. and System-Effectiveness

The evaluation of L.C.C. and system-effectiveness for each alternative is shown in Table 4.12 [Ref.18: p. 37].

Item	Life Cycle Cost(L.C.C)		Choosing Priority Based on Least Cost	System Effectiveness (Scales)	Choosing Priority Based on Greatest Scale
	Undiscounted	Discounted			
UNISYS	\$2,176.000	\$1,994.755	1	$5.1 + \omega$	1
Upgraded Zenith	\$3,772.000	\$3,531.904	2	4.0	3
DELL-310	\$4,256.000	\$4,061.776	3	$5.0 + \omega$	2

Table 4.12 Choosing Priority Based On L.C.C. And System Effectiveness

Table 4.12 reveals that the L.C.C. of UNISYS system is the lowest when undiscounted \$2,176.00. or discounted \$1,994.75, and also is the most effective. Therefore, it is the best alternative. But there exists some trade-off between upgrading the Zenith system and purchasing the DELL-310 system. The difference of L.C.C. between the two alternatives undiscounted is \$484 (\$4,256 - \$3,772), and when discounted \$529.872 (\$4,061.776 - \$3,531.904). From the cost view, the Zenith upgraded system seems cheaper than the DELL-310 system, because it only upgrades the existing Zenith Z-248 system to a 80386 machine. The 80387 math-coprocessor can be purchased for the Zenith system. Therefore, the cost of a 80387 math-coprocessor (\$683, Zenith Z-516, 80387/16 MHZ) would be added to the upgrade of the Zenith system. Further, if the comparison of upgrading the Zenith to the DELL-310 system is based on equal system performance, then the additional 20 MB harddisk should also be added to the Zenith system.

If the Zenith Z-516 80387/16 MHZ coprocessor is chosen for the upgraded Zenith system, the price of such 80387 math-coprocessor of \$683 should be considered. Furthermore, the additional 20 MB harddisk capacity will cost \$292 (Zenith Z217-22). The resulting lump sum is an undiscounted \$4,747 (\$3,772 + \$975), or discounted \$4,506.904 (\$3,531.904 + \$975). These total costs are larger than the \$4,256 and \$4,061.776 of DELL-310 system respectively. Since the performance is equal, the DELL-310 system would be preferred.

Therefore, in the overall view, the UNISYS system is cheapest and has the highest scale for measuring the system-effectiveness, so it should be considered first. When considering costs for each system that have equal system performance, the DELL-310 system would be preferred to the upgraded Zenith system.

C. SENSITIVITY ANALYSIS

1. Introduction

Normally, economic analysis involves sensitivity analysis. Sensitivity analysis is a technique to deal with problems related to uncertainty. The "uncertainty" reflects a situation existing in the real economic analysis environment. The probability of parameters or factors in economic analysis may not be known, so the result of economic analysis includes some risk. Most of the time, the economic analysis will include some assumptions that involve parameters being treated as constants. But sometimes, in the real economic environment, the parameter is variable and not a constant. So the decision makers should consider the sensitivity in the real economic environment due to variation of the parameters. Thus "sensitivity" means the impact of variation of parameters. It may be small enough so it does not affect the result of the analysis or it may be large enough to influence the final decision. The former

impact is called "insensitive" and the latter impact "sensitive". Sensitivity analysis makes the economic analysis flexible with respect to the parameters addressed.

2. Steps In Performing A Sensitivity Analysis

The sensitivity analysis has several steps to follow. Figure 4.21 shows the basic structure of the analysis.

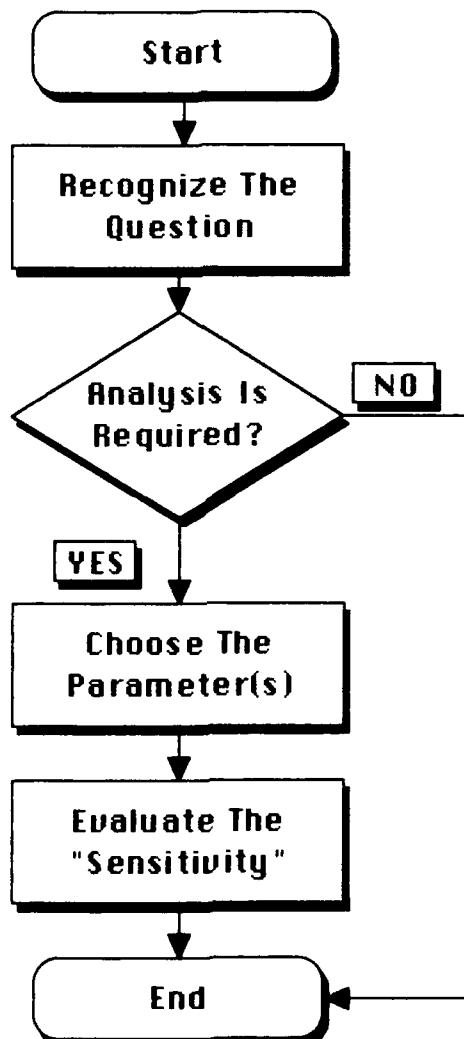


Figure 4.21 The Process Of Sensitivity Analysis

The first step "recognize the question" is to decide whether the sensitivity analysis is required. If (a) the result of economic analysis is clearly that one alternative is superior to the other, (b) there exists significant difference of costs or benefits between each alternative, and (c) all parameters are well defined and "certain", then sensitivity analysis is not required.

The second step, "choose the parameter(s)" means "uncertainty" exists then one or more uncertain parameters should be tested. The "*Naval Data Automation*" suggests the some or all of the following parameters are to examined :

a. Cost Estimates.

Increasing or decreasing major cost elements, which have significant impact on the present value cost. Such cost could be the price to the labor, or the cost of supplies of operation etc.

b. Length of System Economic Life

The shorter or longer system economic life.

c. Volume, Mix, or pattern of workload.

The variation in the estimated volume, mix or pattern of work load.

d. Requirements.

The change in requirements resulting from either the need of regulation or change in function or organizational structure etc.

e. Configuration of Equipment Or Software.

The variation in configuration of hardware, software, data communications and other facilities.

f. Assumptions.

The assumptions concerning requirements, operations, facilities, or software, etc. [Ref. 8: pp. 17.1-17.2].

In this thesis, the result of analysis shows that the L.C.C of upgraded Zenith system is about 1.73 times of that of UNISYS system (\$3.772/\$2.176), and the DELL-

310 system is about twice of that of UNISYS system (\$4,256/\$2,176 about 1.955). The reasons are: (a) the procurement cost of the upgraded Zenith (\$2,788) is about 1.82 times that of UNISYS system (\$1,531) and the DELL-310 system \$ 3,460 is about 2.26 times over the \$1,531 of the UNISYS system (b) We assume only a five year economic life of the system. Therefore, two interesting sensitivity questions result: (a). If the economic life of each alternative can be longer, what will be the impact on choice ? (b). If the L.C.C (or procurement cost) of the upgraded Zenith system and the DELL-310 system would be cheaper, how would it affect the economic analysis?. These two factors, economic life and L.C.C., will be addressed in the next section.

The last step, "evaluate the sensitivity" means testing the parameters individually and determining its effect on the analysis. If the effect is significant then the parameter is important so the decision makers cannot ignore it; if the effect is small- "insensitive" then the decision would not be changed at all.

3. Execution Of Sensitivity Analysis

(a). The Approach for Performing Sensitivity Analysis

Generally, there are different ways to perform the sensitivity analysis, either setting the tables to check the difference of results of different inputs introduced in analysis, or drawing the graphics to check the sensitivity. The break-even point analysis is one type of graphic method to show the sensitivity analysis. It is useful for determining the point at which a particular factor becomes sensitive. This method is fairly simple, effective and may be widely used. The method is: (a) set the cost equation for two different alternatives equal to each other, then (b) solve the unknown variable. For example, L.C.C. of UNISYS system can be set to equal that

of the upgraded Zenith system (or equal to that of DELL-310 system) and solved for the unknown variable-economic life.

This study will use the special sensitivity analysis method (i.e. break-even analysis method) to examine the sensitivity of changing the economic life by graphics (Figure 4.22) and use general sensitivity analysis method to perform the analysis by tables (Tables 4.14 and 4.15) in next paragraph.

(b). The Execution Of Sensitivity Analysis

(1). Test By Change Of The Economic Life

When performing the break-even method for sensitivity analysis to test the economic life parameter, it will be the only variable and all other data will be held as constant. Table 4.13 gives the information to perform the break-even analysis.

Cost /System	UNISYS	Upgraded Zenith	DELL-310
Non-recurring Procurement Cost	\$ 1,531.00	\$3,763.00	\$3,460.00
Recurrent Annual O&M Cost	\$215.00	\$246.00	\$199.00
Economic Life (Years)	5	5	5

Table 4.13 The New Cost Data And Economic Life Of Each Alternative ⁹

⁹ The \$3,763 new non-recurring cost for Upgraded Zenith system is added by \$2,788 plus \$975 of Zenith Z-516 80387 math-coprocessor (\$683) and additional 20 MB harddisk (\$292). For easy computation, the break-even analysis will use the undiscounted cost instead of the discounted cost.

Table 4.13 reveals the important fact that the non-recurring procurement and recurring O&M costs of UNISYS are cheaper than that of the upgraded Zenith system (\$1,531 vs \$3,763 and \$215 vs \$246). Regardless of the change in economic life, the cost of UNISYS system is always better than the upgraded Zenith system even without 80387 math-coprocessor. There will not be any break-even points between these two systems. So the break-even analysis is not necessary for dealing with this situation.

By checking the cost of UNISYS and DELL-310 system, the O&M cost of DELL-310 is cheaper than that of UNISYS, so there may be some break point. The Equation 4.5, its calculation and Figure 4.22 showing the plot of break-even analysis are illustrated as follows:

$$\$1,531 + \$215X = \$3,460 + \$199X \quad (\text{Equation 4.5})$$

X: is the unknown economic life (year)

The solution is: $(\$3,460 - \$1,531) = (\$215 - \$199) X$

$$X = \frac{\$1,929}{\$16} \approx 120.5625 \text{ (Years)}$$

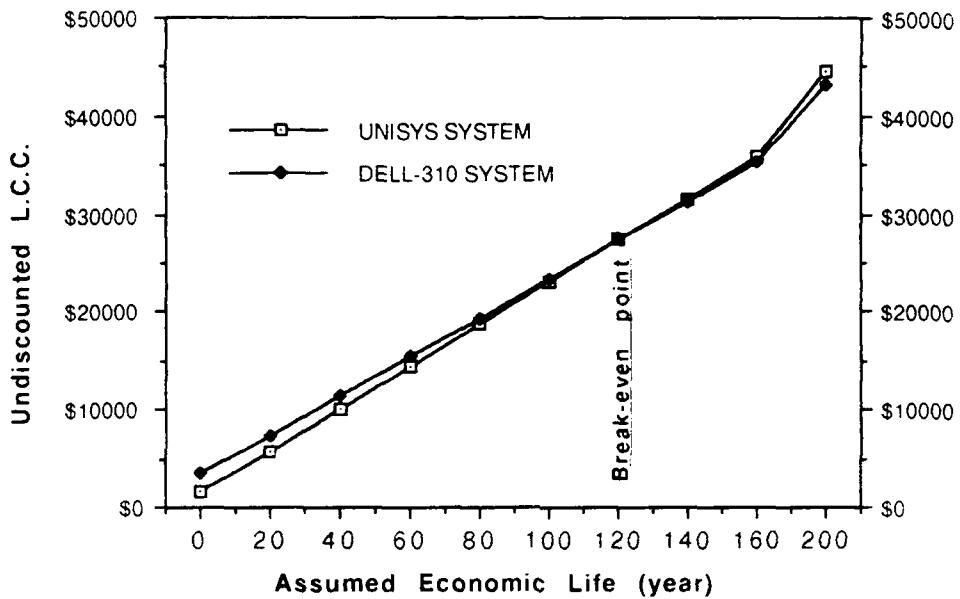


Figure 4.22 The Break-Even Analysis Of UNISYS And DELL-310 System

The analysis shows that one break-even point occurs at the economic life at about 120 years. At that point the L.C.C. cost of UNISYS and DELL-310 system will be the same at about \$27,452. however, a computer system will not last that long, thus the solution is infeasible. So, the economic life will be regarded as "insensitive" to the analysis of result. The decision remains the same.

(2). Test By The Reduction Of Cost

As in the previous discussion, the study will be conducted for the reduction of cost for the upgraded Zenith and DELL-310 system to check for "sensitivity", to determine at which cost reduction can the two systems compete with that of UNISYS system. During the computation, the cost of the UNISYS system will be treated as a base without change in cost. The cost reduction for DELL-310 system will be assigned to 10%, 25%, 50% and 60% of the undiscounted L.C.C. The economic life will still five years. Tables 4.14-4.15 illustrate the results.

Year	UNISYS Undiscounted Cost (No Change)	Upgraded Zenith Reduction			
		10 %	25%	50%	60%
0	\$1,531,000	\$3,386.700	\$2,822.250	\$1,881.500	\$1,505.200
1	\$0.000	\$0.000	\$0.000	\$0.000	\$0.000
2	\$0.000	\$221.400	\$184.500	\$123.000	\$98.400
3	\$215.000	\$221.400	\$184.500	\$123.000	\$98.400
4	\$215.000	\$221.400	\$184.500	\$123.000	\$98.400
5	\$215.000	\$221.400	\$184.500	\$123.000	\$98.400
Total	\$2,176.000	\$4,272.300	\$3,560.250	\$2,373.500	\$1,898.800

Table 4.14 The Sensitivity Analysis Of Undiscounted Cost Reduction¹⁰ :
The Cost Reduction Of Upgraded Zenith vs No Change Of UNISYS

¹⁰ Obviously, a reduction of more than 60% is required to meet the decision.

Year	UNISYS Undiscounted Cost (No Change)	DELL-310 Reduction			
		10 %	25 %	50 %	60 %
0	\$1,531.000	\$3,114.000	\$2,595.000	\$1,730.000	\$1,384.000
1	\$0.000	\$0.000	\$0.000	\$0.000	\$0.000
2	\$0.000	\$179.100	\$149.250	\$99.500	\$79.600
3	\$215.000	\$179.100	\$149.250	\$99.500	\$79.600
4	\$215.000	\$179.100	\$149.250	\$99.500	\$79.600
5	\$215.000	\$179.100	\$149.250	\$99.500	\$79.600
Total	\$2,176.000	\$3,830.400	\$3,192.000	\$2,128.000	\$1,702.400

Table 4.15 The Sensitivity Analysis Of Undiscounted Cost Reduction¹¹:
The Cost Reduction Of DELL-310 Vs. No Change Of UNISYS

(c). About The Discount Rate

The difference of annual O&M cost between the UNISYS system and the DELL-310 system is small, \$26 (\$215 - \$199) and the difference of non-recurring procurement cost is large: \$1,929 (\$3460 - \$ 1,531). The economic life is short. Therefore, even with no discounting, the L.C.C. of DELL-310 system will always be higher than that of the UNISYS system. Thus, the discount rate is an "insensitive" parameter.

¹¹ Obviously, a reduction of more than 50% is required to meet the decision

D. CONCLUSIONS

The result of economic analysis shows the UNISYS system to be the least expensive and most system-effective. The price of each unit is an undiscounted \$2,176 or discounted \$1,994 for five years of economic life. A total cost for 20 units to upgrade the OR-PC laboratory is \$43,520 (or \$39,880 undiscounted), within the budget set for this discussion.

The sensitivity analysis reveals the following points. First, in break-even analysis, the economic life parameter is insensitive. Second, the cost reduction parameter is also insensitive to the analysis result unless the cost reduction is over 50%. Third, the discount rate is also insensitive, therefore the conclusion remains the same.

E. RECOMMENDATIONS

Based on the results of the economic analysis, and the sensitivity analysis, the UNISYS system is the best choice. It has at least equal performance, about equal maintainability and Operations and Maintenance (O&M) cost but has substantially lower procurement cost.

For the three machines compared, the O&M cost is small. The machines are reliable and only a few malfunctions have been experienced in the OR PC laboratory. The low procurement cost of the UNISYS system is due to the DOD contract "DD1155".

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Appendix. QUESTIONNAIRE FORM

In our OR department laboratory the PC-AT 16 bit machines (ZENITH Z-248 AT) will be upgraded to 32 bit 386 machines in the near future. This is a thesis research survey designed to ensure we buy a system that meets your needs. Please take a couple of minutes to answer this questionnaire and return it to our OR curricular office (R230) by 8 FEB 90 (Thur). Thank you.

Please answer the following questions regarding the processing time you are experiencing on the OR Computer Laboratory systems.

1. I operate the OR Computer Laboratory in the following environments:

- a)Word Perfect
- b)GAMS
- c)APL
- d)STATGRAPHICS
- e)LINDO
- f)HARVARD GRAPHICS

2. If the speed of the OR Computer Laboratory systems were increased I would also operate in the following additional environments:

- a)Word Perfect
- b)GAMS
- c)APL
- d)STATGRAPHICS
- e)LINDO
- f)HARVARD GRAPHICS
- g)other environments

3. Please characterize the speed of operation in each of the environments you operate in:

Word Perfect:

- 1)adequate
- 2)slow but acceptable
- 3)very slow
- 4)prohibitively slow

GAMS:

- 1)adequate
- 2)slow but acceptable
- 3)very slow
- 4)prohibitively slow

APL:

- 1)adequate
- 2)slow but acceptable
- 3)very slow
- 4)prohibitively slow

STATGRAPHICS:

- 1)adequate
- 2)slow but acceptable
- 3)very slow
- 4)prohibitively slow

LINDO:

- 1)adequate
- 2)slow but acceptable
- 3)very slow
- 4)prohibitively slow

HARVARD GRAPHICS :

- 1)adequate
- 2)slow but acceptable
- 3)very slow
- 4)prohibitively slow

4. Please characterize any other changes in the environment you would suggest:

Date : 4 FEB 1990

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